

A DOUBLE-DECK BUCK-BOOST CONVERTER WITH SOFT SWITCHING OPERATION FOR RENEWABLE ENERGY APPLICATIONS

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Abstract- This paper presents a novel two-stage buck-boost converter with a soft switching operation for RE applications. The proposed converter is constructed of two identical buck-boost converters working in parallel. The converter units are connected to each other by an inductor as a bridge. This inductor plays an important role in the soft switching operation of the converter by maintaining the voltage applied to switches at zero at switching intervals. Zero voltage switching method of control is being used for switching. This method of switching proposed converter is efficient in the reduction of switching losses and improvement in efficiency of converter. Moreover, because of the parallel operation of two identical converters, the output voltage and the input current contain fewer ripples than those of a single converter with the same specifications. Also, utilizing only one inductor as an extra element to achieve this goal makes the proposed converter more economical and reliable with a simpler structure. The detailed analysis of the circuit operation is provided in eight modes. The performance of the proposed converter is also analyzed by using it in wind power generation system. The proposed converter is simulated in MATLAB/Simlink platform.

Index Terms- DC-link voltage balance, Zero voltage switching, Renewable Energy (RE).

I. INTRODUCTION

DC/DC converters are used for many purposes when the conversion between two dc voltage levels such as electrical vehicles, active filters, power factor correction circuits, distributed generations, dc/dc regulated power supplies, etc., is required [1]–[3]. These types of converters are divided into several types depending on the increase or decrease of the output voltage level with respect to the input voltage. This paper focuses on the buck-boost dc/dc converters which can operate in either buck or boost modes, i.e., they can be used in both step-up and down applications. Another counterpart of these converters is the Cuk converter with a large number of circuit elements in its structure. The main application of step-up/down converters is in regulated dc power supplies, where the output negative polarity may be desired with respect to the common terminal of the input voltage supply.

The efficiency of the dc/dc converters is an important issue which has received great attention in literature works. In this regard, various control strategies and converter topologies are proposed for the soft switching operation of the converters to achieve minimum switching losses leading to more efficient

operations [1], [4]–[6]. Soft switching techniques utilizing the features of Zero-Voltage Switching (ZVS) or Zero-Current Switching (ZCS) substantially reduce the switching losses [7]–[10]. Some of these approaches include active clamps [11], and passive and active snubbers [12]–[14]. In some cases, a combination of ZVS and ZCS techniques has also been discussed [12], [15], [16]. Nowadays, interleaved converters are utilized in many applications and provide many advantages such as increasing efficiency, reducing the voltage and current ripple, and supplying more load power. The ZVS operation of the parallel boost converters has been investigated. The inductor placed between two parallel converters is called the interleaved inductor and displaces the resonating current between two converters at particular time intervals in order to perform the soft switching operation of the set. The operation procedure of this kind of converters is described in two sets of symmetric scenarios depending on the situation of the resonating current.

In this paper, a double-deck buck-boost converter with an effective ZVS technique is proposed. The operational principles of the proposed converter are surveyed and summarized in eight modes. It is shown that the switching process can perform with the minimum losses by applying the gate signals at particular time intervals. Moreover, it is also concluded that utilizing of two converters in parallel causes less ripple in the output load voltage. In addition, the fact of using only one inductor as an extra element to achieve the main goal of this paper suggests that the proposed converter is more economical than the soft switched converters by adopting coupled inductors or transformers.

II. OPERATION OF CONVERTER

The configuration of the proposed converter is shown in Fig. 1. It consists of two identical buck-boost converters working in parallel. The source and the output capacitor C_o are shared between two converters. The inductor L_s is placed in parallel with two switches, as shown in Fig.1. This element plays an important role in main plot of the soft switching manner of the converter. It discharges the intrinsic capacitances of the switches by creating a resonant circuit. Then, the switching could be done

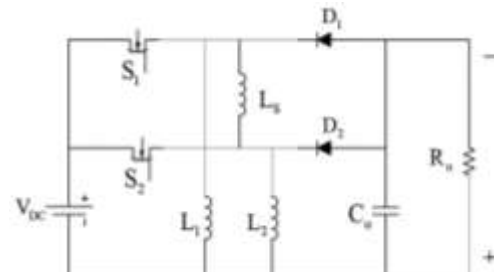


Fig. 1. Configuration of the parallel buck-boost converters.

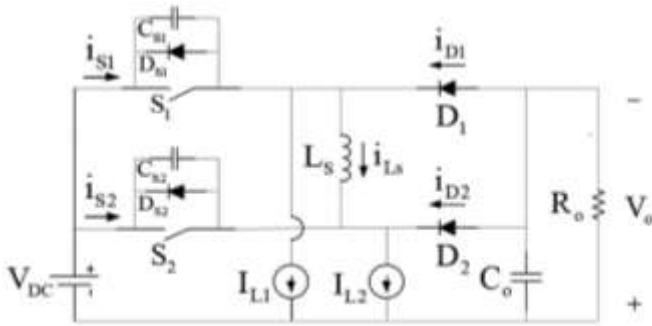


Fig. 2. Equivalent circuit diagram

When the intrinsic anti parallel diodes of the switches conduct the negative half-cycle of this resonating current and the voltage on the switches is clamped at zero. Two power MOSFETs, S1 and S2, are used for high frequency switching with the same switching frequency. The duty ratio D for each of the switches is identical and slightly greater than 0.5 to create overlapping intervals. It is assumed that the converters operate in the continuous current mode (CCM). The equivalent circuit shown in Fig. 2 is utilized to describe the procedure of the proposed converter operation. To simplify the analysis, it is considered that the currents of inductors L1 and L2 and also the output currents are constant, and modeled by a constant current source, as shown in Fig. 2. Moreover, the output voltage is assumed to be almost fixed because of the large output capacitor Co. To describe how the ZVS is achieved, the detailed models of the power MOSFETs are utilized. They consist of the intrinsic anti parallel diode and capacitance in parallel with an ideal switch.

The operation procedure of the converter can be presented in eight modes depending on the different statuses of the switches. Because the two buck-boost converters are completely identical, all the circuit elements such as L1, L2, CS1, and CS2 have the same values. In all stages, the forward voltage drops on diodes D1 and D2, and switches S1 and S2 are considered negligible. The equivalent circuit of each mode is shown in Fig.3. The elements which are conduct are distinguished with the elements that are not. The theoretical waveforms related to each mode are demonstrated in Fig. 4.

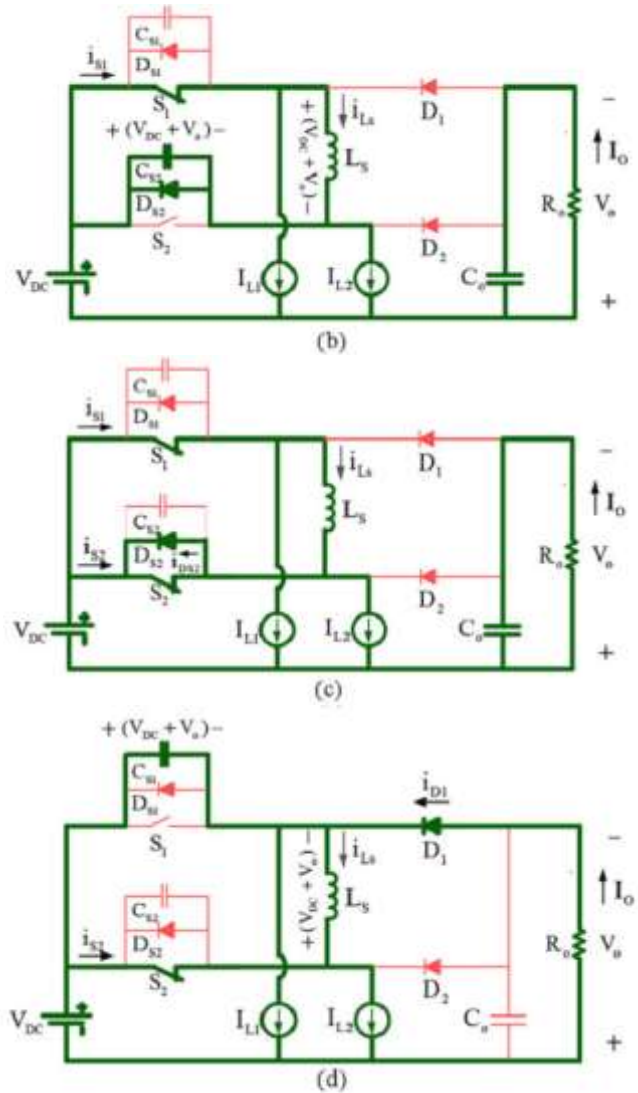
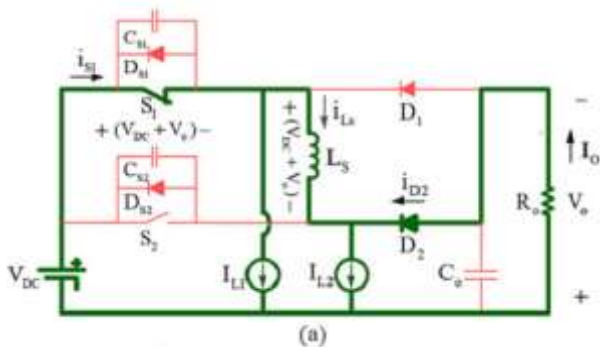


Fig. 3. Equivalent circuit diagrams of different operation modes. (a) Mode I. (b) Mode II. (c) Mode III. (d) Mode IV.

Mode I: $t_0 < t < t_1$: to describe the first mode, it is considered that the diode D2 free wheels the load current I_o . So, according to Fig. 3(a), the diode D2 current is equal to $I_{L1} + I_{L2}$ and the current I_{L1} passes through the inductor L_s , reversely. Mode I begin when the switch S1 is closed and D2 freewheeling current is decreasing to zero. Therefore, the voltage $V_{DC} + V_o$ which was clamped on the capacitor CS2 is imposed on the inductor L_s by the polarity depicted. Therefore, the inductor current i_{Ls} increases linearly from $-I_{L1}$ to I_{L2} , as depicted in Fig. 4. Meanwhile, i_{S1} increases linearly simultaneous with the i_{Ls} increment. As i_{Ls} reaches zero, the current I_{L1} passes through the switch S1. When i_{Ls} rises up to I_{L2} , i_{S1} reaches $I_{L1} + I_{L2}$. At the end, the freewheeling current of D2 reaches zero, as shown in Fig. 4. On whole, V_{CS2} is considered to be constant and equal to $V_{DC} + V_o$ in this process.

Mode II— $t_1 < t < t_2$: this mode starts when the freewheeling current of D2 reaches zero. Then, a resonant circuit is formed between C_{S2} and L_s . This resonating current discharges the capacitor CS2 which was clamped on $V_{DC} + V_o$ before entering this mode. After V_{CS2} decreases to zero, DS2 will be forward



biased to conduct the resumption of the resonant current cycle. Now, both of the resonant current and the inductor current flow through the interleaved inductor L_S ; therefore, i_{L_S} becomes a small bit larger than I_{L_2} , as illustrated in Fig. 4. Fig. 3(b) shows the equivalent circuit diagram of this mode.

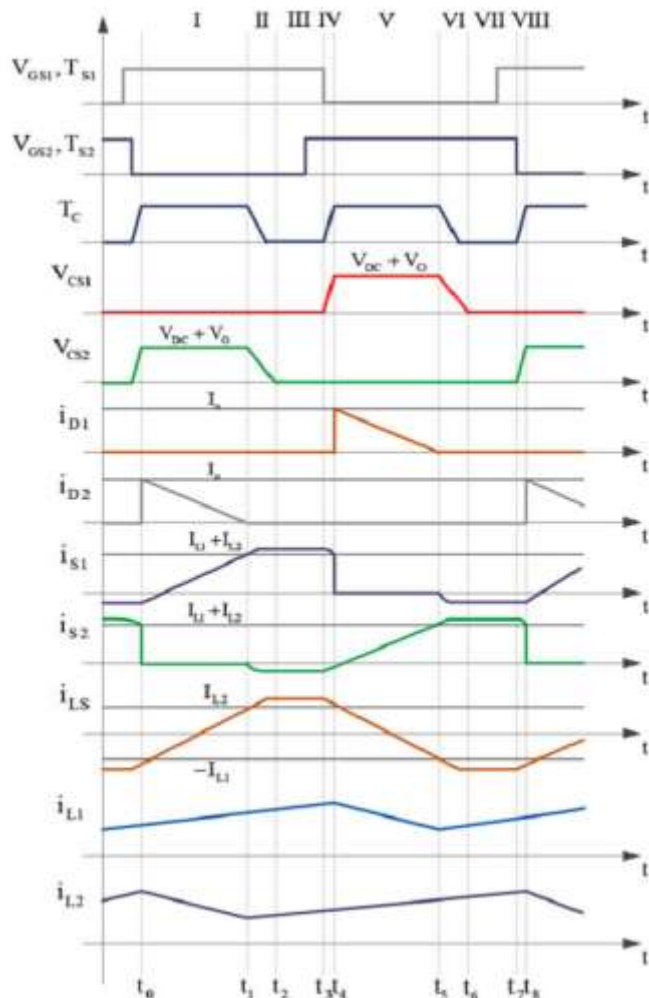


Fig. 4. Theoretical waveforms of the key components.

Mode III— $t_2 < t < t_3$: at the beginning of this mode, DS_2 whose voltage was fixed at zero begins to conduct a small current reversely through the switch S_2 . This current is the difference between i_{L_S} and I_{L_2} . Therefore, the voltage across the switch S_2 which is the same as V_{CS2} becomes equal to zero as shown in Fig. 4. Thus, it is a great opportunity to apply the gate signal of the switch S_2 as V_{GS2} during this interval. So, the switch S_2 turns ON at the zero voltage.

Mode IV— $t_3 < t < t_4$: at the beginning of this mode, the gating signal of the switch S_1 is removed and it is turned OFF. Therefore, the intrinsic capacitor CS_1 is charged rapidly to $V_{DC} + V_O$ by the sum of currents I_{L_2} and I_{L_1} . According to Fig. 4, along with an increase in the CS_1 voltage, the current i_{L_S} begins to decrease and reverses its direction toward $-I_{L_1}$ because V_{CS1} is imposed on the inductor L_S . By applying the KVL to the end of this mode, the voltage of diode D_1 becomes equal to zero. Thus, it begins to freewheel the load current. Due

to the symmetry of the proposed converter, Modes V to VIII could be summarized in similar scenarios for the switch S_1 .

III. MATHEMATICAL MODELLING

As it was mentioned in above, the duty ratio of the switches must be considered slightly greater than 0.5. Therefore, it causes a small overlap between the gating signals of the switches. But, the effective duty ratio is larger than that of the duty ratio D of each of switches S_1 and S_2 . For instance, the conversion unit 1 is effectively turned ON in Modes I to III, and also in Modes VI to VIII, a small negative current passes through S_1 . Therefore, it is effectively turned OFF just in Mode V. Similarly, the conversion unit 2 is effectively turned OFF in Mode I. According to Fig. 4, since the effective turn off interval is the commutation time of the inductor L_S , the effective duty ratio D_E can be represented as

$$D_E = \frac{T_S - T_C}{T_S}$$

On the other hand, the relations between the output and input values of a usual buck-boost converter in the CCM are stated as follows:

$$V_O = \frac{D_E}{1 - D_E} V_{DC}$$

$$I_O = \frac{1 - D_E}{D_E} I_{in}$$

IV. SIMULATION RESULTS

The proposed Double Deck buck boost converter performance is studied in MATLAB/SIMULINK platform. The Fig 5(a), (b) shows the simulated circuit proposed converter. The Double Deck Buck Boost converter is implemented in wind power generation system. Wind power generation system produced electrical power with maximum voltage of 320V. The ac is rectified into dc using diode bridge rectifier, the dc voltage is 300V. This is given as input for the double deck buck boost converter and it is boosted to average value of 750V. The space vector PWM controlled three phase Voltage Source Inverter is used to convert dc into ac; the output rms voltage is 400V. The THD of inverter voltage is 5.60%.

Table 1. Simulation Parameters

Circuit Parameters	Value
Inductors L_1 and L_2	300 μ H
Inductor L_S	80 μ H
Capacitor C_O	200 μ F
Rectifier Capacitor	0.8mF
DC Bus Capacitor	400 μ F

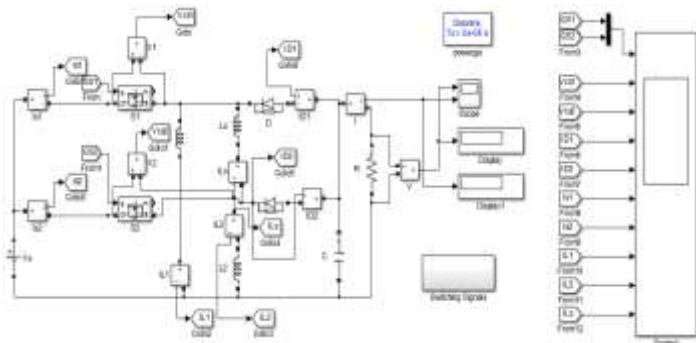


Fig 5. Simulation of Double deck buck boost converter

The switching frequency of 2.5 kHz is used to switch the circuit power switches and to observe the practical waveforms of circuit parameters. The waveforms under boost operation are shown in fig 6. The input dc voltage is 100V, the converter boosted up to 413.9V and the waveforms under buck operation are shown in fig 7. The input voltage is 100V and the buck in voltage is 65.2V at 350Hz

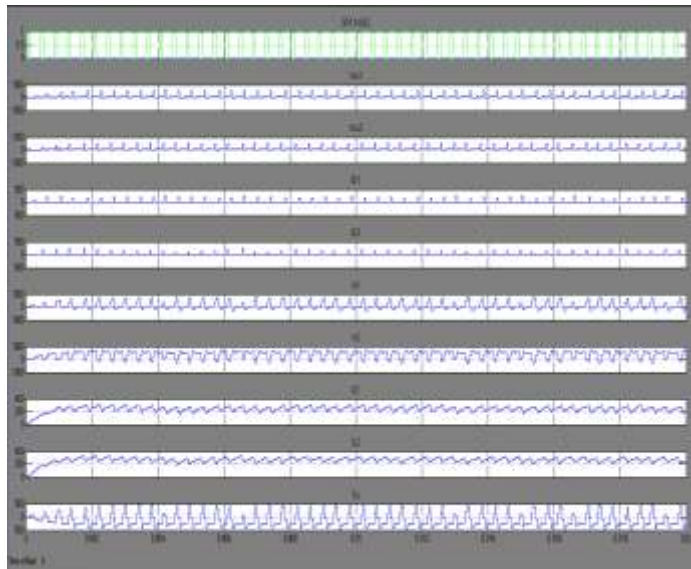


Fig 6. Waveforms of the typical circuit parameters during Boost operation

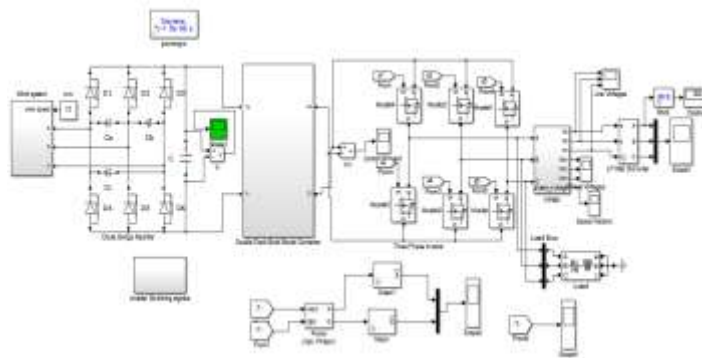


Fig 7. Simulation of Double deck buck boost converter in wind power generation

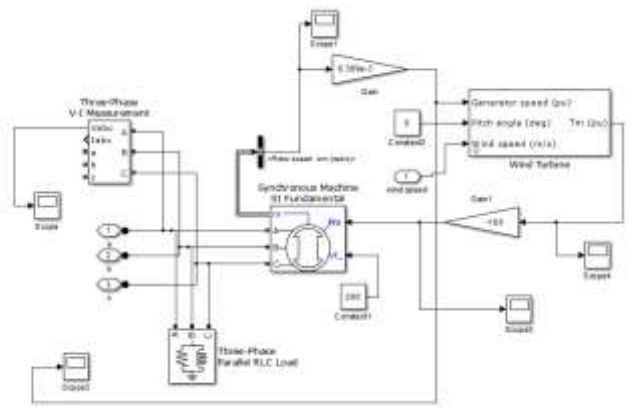


Fig 8. Simulation diagram of wind power generation system

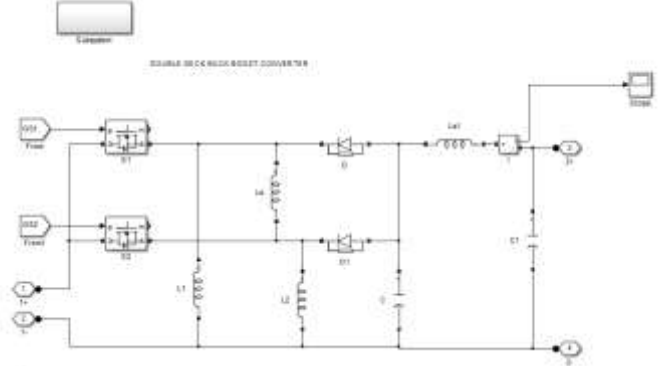


Fig 9. Simulation diagram of double deck buck boost dc-dc converter

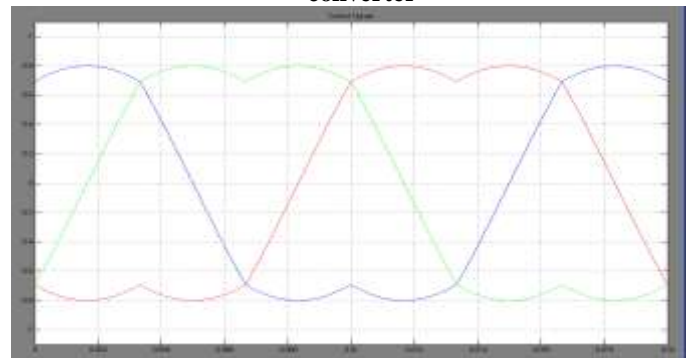


Fig 10. Space Vector Control Signals

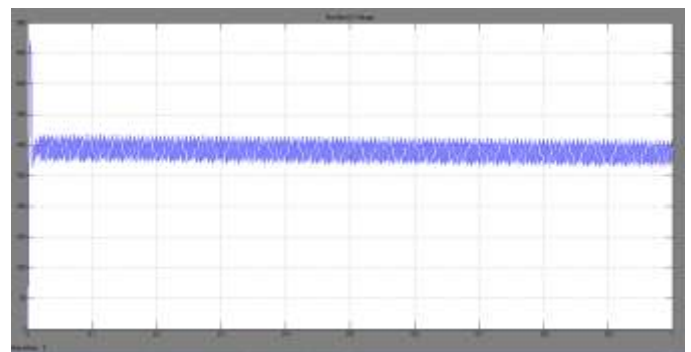


Fig 11. Rectifier output dc voltage of wind generation system

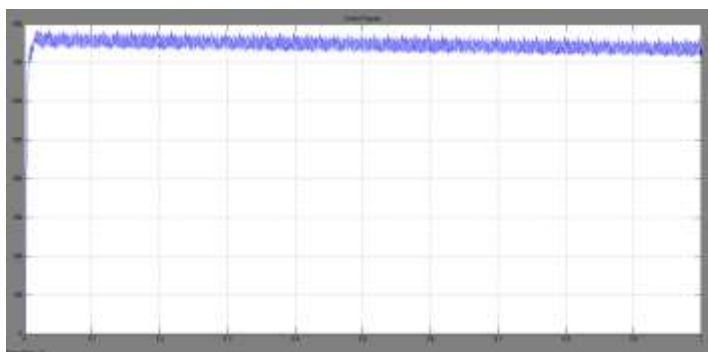


Fig 12. Double deck buck boost converter output voltage

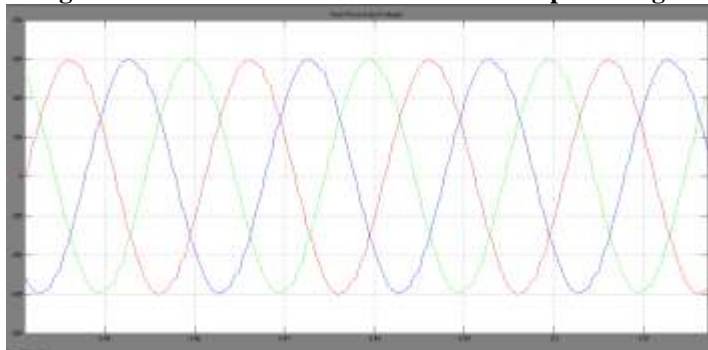


Fig 13. Line to line output Voltages of three phase inverter

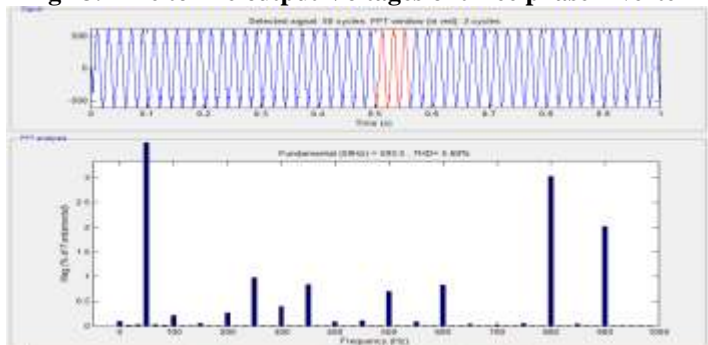


Fig 14. THD of Inverter Voltages

V. CONCLUSION

In this paper, a novel double-stage buck-boost converter with ZVS capability is proposed. The theoretical analysis and design equations are described to achieve the soft switching operation of the proposed converter. This goal could be obtained by just an extra inductor placed between two units as a bridge. Therefore, the reliability of the proposed converter increases due to the simplicity of the proposed structure. It is demonstrated that the output voltage of the converter could be regulated by changing the switching frequency instead of the duty ratio. To investigate the effect of the ZVS technique on the proposed converter efficiency rather than a normal single-stage buck-boost converter, the output power has been changed within the interval of 100–220 W. The results showed that the switching losses were effectively reduced. Therefore, the converter efficiency improved significantly so that it remained greater than 93% in all of the investigated loads. Moreover, it could be concluded that the proposed converter can provide less ripple in the voltage and current of the load and input supply due to the operation of two converters in parallel.

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