A Two Stage Buck – Boost Converter with Soft Switching for Wind Power Applications

Rentapalli Kishore Kumar[1], M Sreenu[2]
[1,2] *Department of EEE, Amrita Sai Institute of Science & Technology, Paritala, Krishna Dt, A.P, India*

***Abstract*- A novel two – stage buck boost converter with soft switching operation for renewable energy applications is proposed in this paper. Two identical buck boost converters connected to each other through an inductor works in parallel in the proposed converter. 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/Simulink platform.**

***Index terms*- DC-link voltage balance, zero voltage switching, Renewable Energy (RE), Buck-boost converter, Induction wind turbine.**

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 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 OFCONVERTER

The configuration of the proposed converter is shown in Fig. 1. It is consist of two identical buck-boost converters working in parallel. The source and the output capacitor Co are shared between two converters. The inductor Ls 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

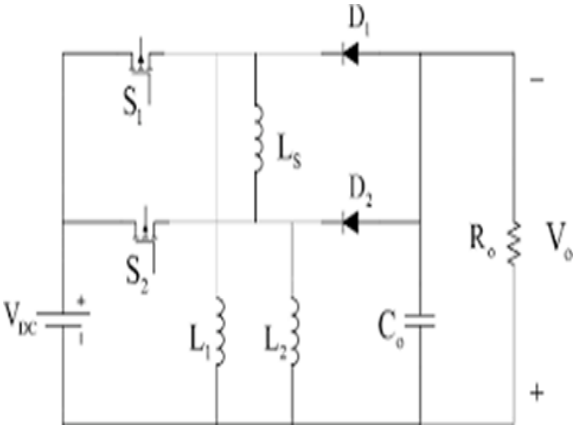


Fig. 1. Configuration of the parallel buck-boost converters

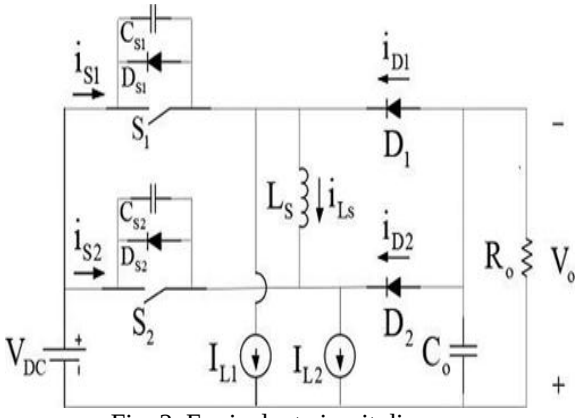
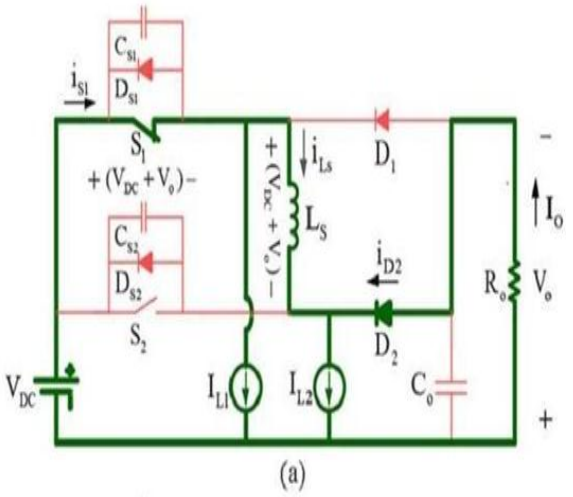


Fig. 2. Equivalent circuit diagram

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 inductorsL1and 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.



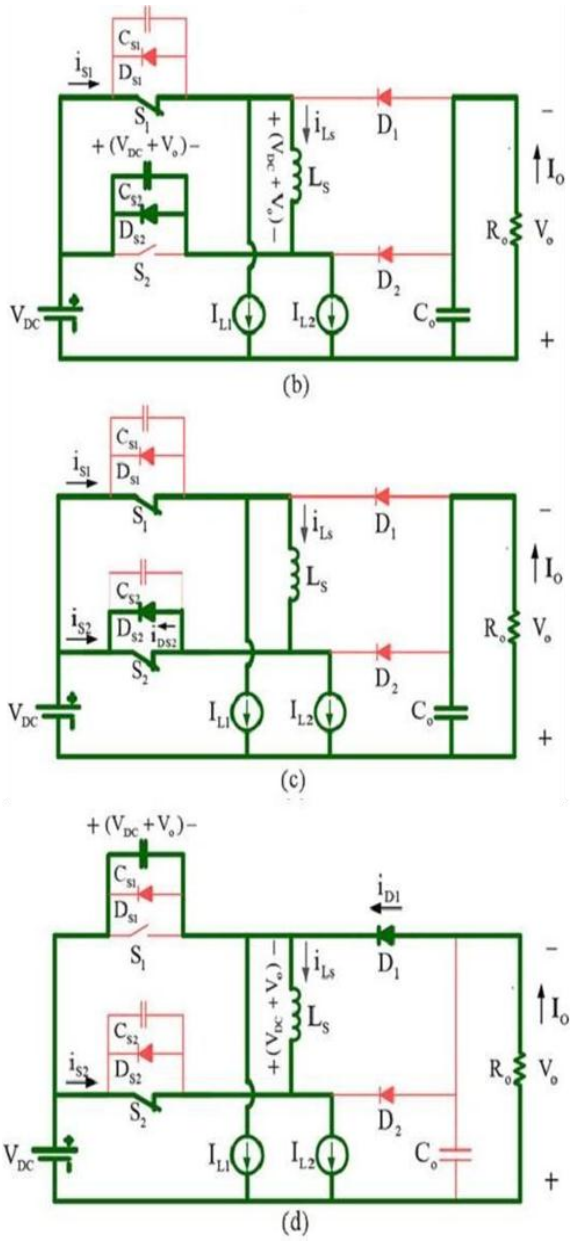


Fig. 3. Equivalent circuit diagrams of different operation modes. (a) Mode I. (b) Mode II. (c) Mode III. (d) Mode IV

Mode I: t0< t < t1: to describe the first mode, it is considered that the diode D2 free wheels the load current Io. So, according to Fig. 3(a), the diode D2current is equal to IL1+IL2 and the current IL1 passes through the inductor LS, reversely. Mode I begin when the switchS1is closed and D2 freewheeling current is decreasing to zero. Therefore, the voltage VDC+VO which was clamped on the capacitor CS2 is imposed on the inductor LS by the polarity depicted. Therefore, the inductor current iLs increases linearly from −IL1 to IL2, as depicted in Fig. 4. Meanwhile, iS1 increases linearly simultaneous with the iLs increment. As iLs reaches zero, the current IL1 passes through the switch S1. When iLs rises up toIL2, iS1 reaches IL1+IL2. At the end, the freewheeling current of D2 reaches zero, as shown in Fig. 4. On whole, VCS2 is considered to be constant and equal to VDC+VO in this process. Mode II— t1 < t < t2: this mode starts when the freewheeling current of D2 reaches zero. Then, a resonant circuit is formed between CS2 and LS. This resonating current discharges the capacitor CS2 which was clamped on VDC+VO before entering this mode. After VCS2 decreases to zero, DS2 will be forward biased to conduct the resumption of the resonant current cycle. Now, both resonant current and the inductor current flow through the interleaved inductor LS; therefore, iLs becomes a small bit larger than IL2, as illustrated in Fig. 4. Fig. 3(b) shows the equivalent circuit diagram of this mode.

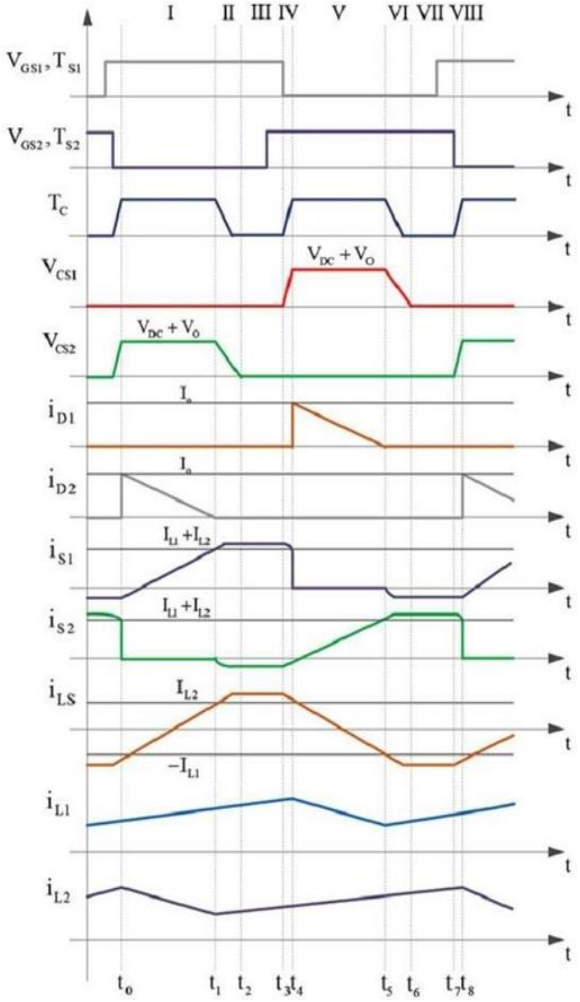


Fig. 4. Theoretical waveforms of the key components

Mode III—t2 <t<t3: at the beginning of this mode, DS2 whose voltage was fixed at zero begins to conduct a small current reversely through the switchS2. This current is the difference betweeniLsandIL2. Therefore, the voltage across the witch S2 which is the same asVCS2 becomes equal to zero as shown in Fig. 4. Thus, it is a great opportunity to apply the gate signal of the switchS2asVGS2during this interval. So, the switchS2 turns ON at the zero voltage.

Mode IV—t3 < t < t4: at the beginning of this mode, the gating signal of the switch S1 is removed and it is turned OFF. Therefore, the intrinsic capacitor CS1 is charged rapidly to

VDC+VO by the sum of currents IL2 and IL1 According to Fig. 4, along with an increase in theCS1 voltage, the current iLs begins to decrease and reverses its direction toward to−IL1 becauseVCS1 is imposed on the inductor LS. By applying the KVL to the end of this mode, the voltage of diodeD1 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 switchS1.

III MATHEMATICALMODELLING

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 switchesS1 andS2. 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 pass through S1. 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 LS, the effective duty ratio DE 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:

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

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

IV. SIMULATIONRESULTS

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 is6.60%.

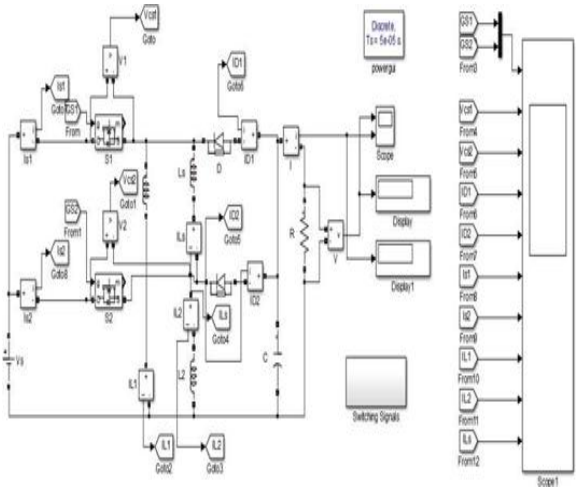
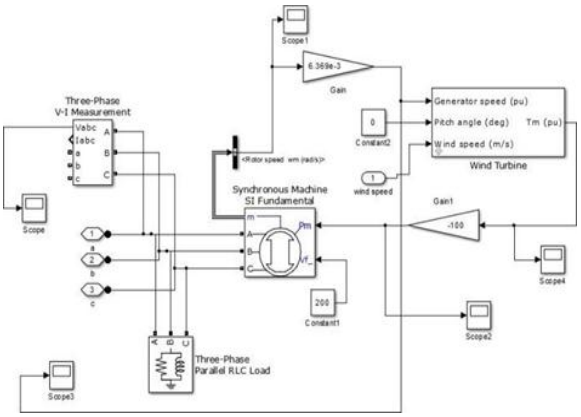


Fig 5. Simulation of Double deck buck boost converter

Table 1. Simulation Parameters

Circuit Parameters	Value
Inductors L_1 and L_2	320µH
Inductor L_S	70µH
Capacitor C_O	310µF
Rectifier Capacitor	0.85mF
DC Bus Capacitor	420µF



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 413.9 and the waveforms under buck operation are shown in fig 7. The input voltage is 100V and the Buck voltage is 65.2V at350Hz

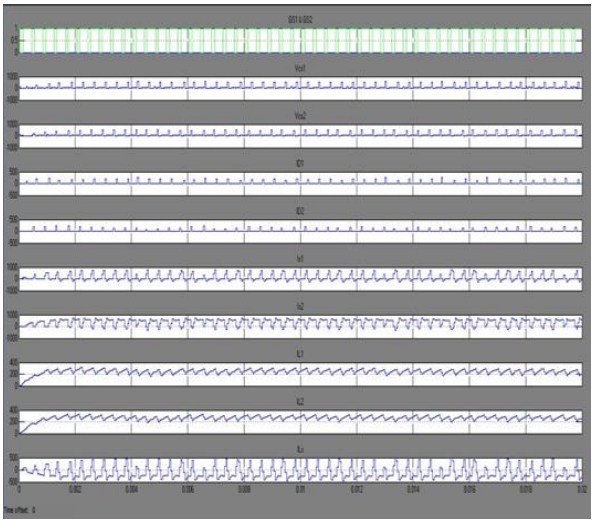


Fig 6. Waveforms of the typical circuit parameters during

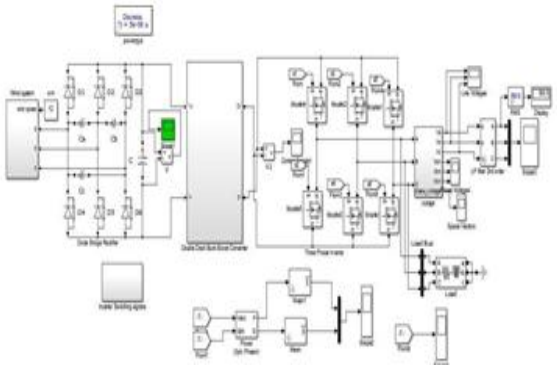


Fig 7. Simulation of Double deck buck boost converter in system wind power generation

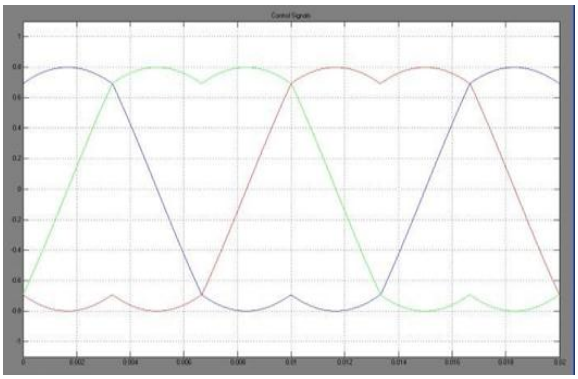


Fig 8. Simulation diagram of wind power generation system

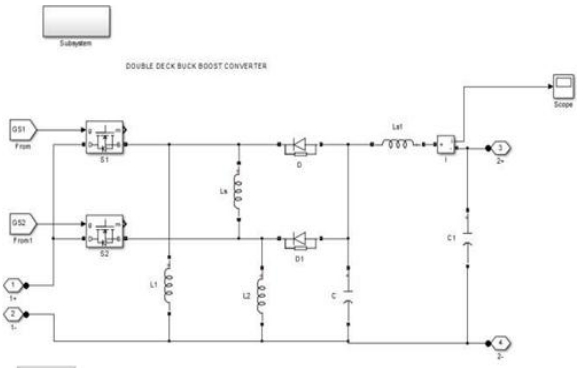


Fig 9. Simulation diagram of double deck buck boost dc -dc converter

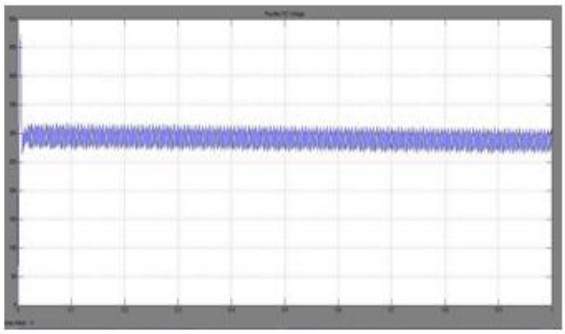


Fig 10. Rectifier output dc voltage of wind generation

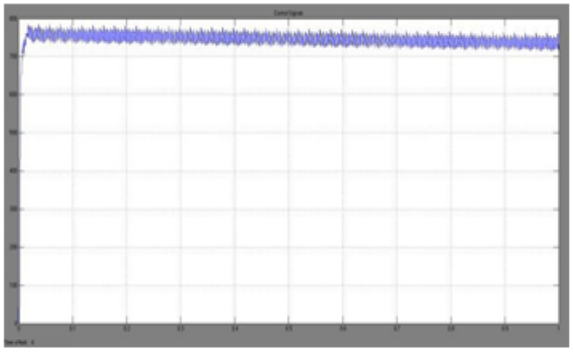


Fig 11. Double deck buck boost converter output voltage

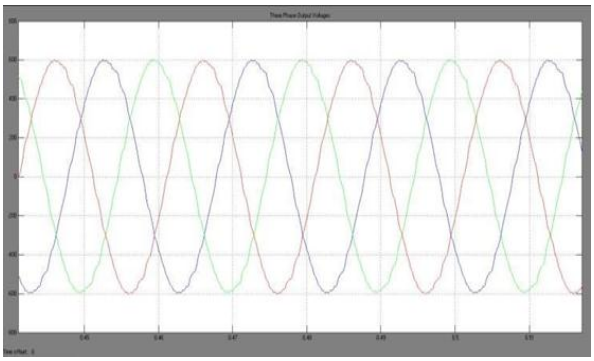


Fig 12. Line to line output Voltages of three phase inverter

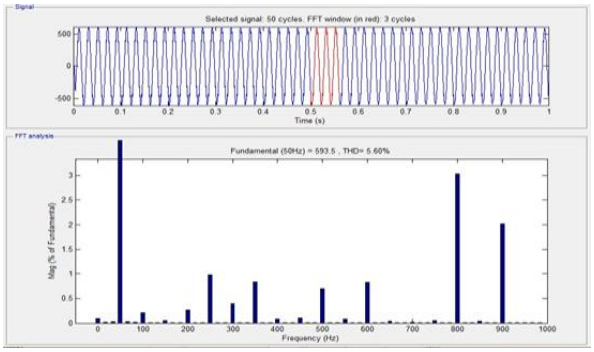


Fig 13. THD of Inverter Voltages

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.

REFERENCES

[1] J. Hong, H. Lee, and K. Nam, “Charging method for the secondary battery in dual-inverter drive systems for electric vehicles,” IEEE Trans. Power Electron., vol. 30, no. 2, pp. 909– 921, Feb.2015.

[2] B. Mahdavikhah and A. Prodic, “Low-volume PFC rectifier based on nonsymmetric multilevel boost converter,” IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1356–1372, Mar.2015.

[3] Q. Shibin, S. T. Cady, A. D. Dominguez-Garcia, and R. C. N. PilawaPodgurski, “A distributed approach to maximum power point tracking for photovoltaic sub module differential power processing,” IEEE Trans. Power Electron., vol. 30, no. 4, pp. 2024–2040, Apr. 2015.

[4] Y. Wang, W. Liu, H. Ma, and L. Chen, “Resonance analysis and soft switching design of isolated boost converter with coupled inductors for vehicle inverter application,” IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1383–1392, Mar.2015.

[5] M. Pavlovsky, G. Guidi, and A. Kawamura, “Buck/boost dc- dc converter topology with soft switching in the whole operating region,” IEEE Trans. Power Electron., vol. 29, no. 2, pp. 851–862, Feb.2014.

[6] Y.-T. Chen, S.-M. Shiu, and R.-H. Liang, “Analysis and design of a zero-voltage-switching and zero-current-switching interleaved boost converter,” IEEE Trans. Power Electron., vol. 27, no. 1, pp. 161–173, Jan.2012.

[7] B. P. Divakar, K. W. E. Cheng, and D. Sutanto, “Zero- voltage and zerocurrent switching buck-boost converter with low voltage and current stresses,”IETPower Electron., vol. 1, no. 3, pp. 297–304, Sep.2008.

[8] E. M. Amiri, J. S. Moghani, G. B. Gharehpetian, and S. S. H. Yazdi, “Novel two stage buck-boost converter with zero-voltage- transition operation,” presented at the5th Power Electron., Drive Syst. Technol. Conf., Tehran, Iran, 2014, pp.143–147.

[9] E.-H. Kim and B.-H. Kwon, “Zero-voltage and zero-current switching full bridge converter with secondary resonance,” IEEE Trans. Ind. Electron., vol. 57, no. 3, pp. 1017–1025, Mar.2010.

[10] B. R. Lin and S. K. Chung, "New parallel ZVS converter with less active switches and smaller output inductance," IEEE Trans. Power Electron., vol. 29, no. 7, pp. 3297–3307, Jul.2014.

[11] B. Gu, J. Dominic, B. Chen, L. Zhang, and J.-S. Lai, "Hybrid transformer ZVS/ZCS DC–DC converter with optimized magnetics and improved power devices utilization for photovoltaic module applications," IEEE Trans. Power Electron., vol. 30, no. 4, pp. 2127–2136, Jun.2014.

[12] Y. Jiao, S. Lu, and F. C. Lee, "Switching performance optimization of a high power high frequency three-level active neutral point clamped phase leg," IEEE Trans. Power Electron., vol. 29, no. 7, pp. 3255–3266, Jul.2014.

[13] M. L. da S Martins, C. M. de O Stein, J. L. Russi, J. R. Pinheiro, and H. L. Hey, "Zero-current zero-voltage transition inverters with magnetically coupled auxiliary circuits: Analysis and experimental results,"IETPower Electron., vol. 4, no. 9, pp. 968–978, Nov.2011.

[14] L. Chen, H. Hu, Q. Zhang, A. Amirahmadi, and I. Batarseh, "A boundary mode forward flyback converter with an efficient active LC snubber circuit," IEEE Trans. Power Electron., vol. 29, no. 6, pp. 2944–2958, Jun.2014.

[15] C. Jingquan, D. Maksimovic, and R. W. Erickson, "Analysis and design of a low-stress buck-boost converter in universal- input PFC applications," IEEE Trans. Power Electron., vol. 21, no. 2, pp. 320–329, Mar. 2006.

[16] M. Pavlovsky, G. Guidi, and A. Kawamura, "Buck/boost dc-dc converter topology with soft switching in the whole operating region," IEEE Trans. Power Electron., vol. 29, no. 2, pp. 851–862, Feb.2014

AUTHORS

First Author –Rentapalli Kishore Kumar, he received his B.Tech degree in Electrical and Electronics Engineering from Amrita Sai Institute of Science and Technology, Paritala, A.P, India. He is currently pursuing M.Tech Power Electronics in Amrita Sai Institute of Science and Technology, Paritala, A.P, India. His interested research areas are Power Electronic Applications to ASDs.

Second Author – M Sreenu, he received his B.Tech degree in Electrical and Electronics Engineering from SSN Engineering college, Ongole (A.P), India, in 2009.M.Tech degree Rajeev Gandhi Memorial Institute of Science and Technology (R.G.H.M.I.T), Nandyal (A.P), India, in 2013. He is currently working as a Assistant Professor in Amrita Sai Institute of Science and Technology, Paritala, A.P, India. His interested research areas are Power Electronics & Drives, Power Systems