DEVELOPMENT OF TWO-SWITCH BUCK-BOOST CONVERTER WITH SOFT-SWITCHING

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Abstract : The two-switch buck-boost converter (TSBB) can be operated in four modes: buck, boost and buck-boost modes. This paper introduces the implementation of the soft-switching (ZVS) to the two-switch buck-boost converter in boost mode and buck-boost (boost) mode. The design and analysis is made and presented. The results are verified through simulation using MATLAB

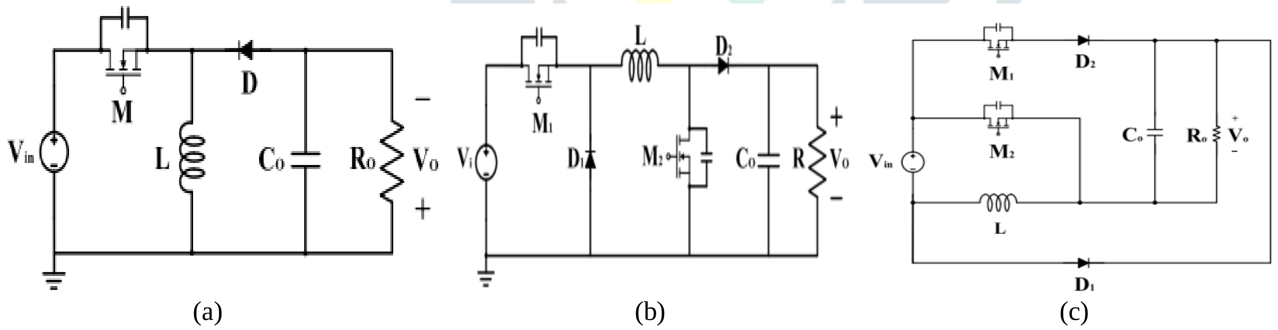
IndexTerms **- Buck-boost converter, Two-switch buck-boost converter, Soft-switching, Zero-voltage switching.**

I. INTRODUCTION

The DC-Dc converters play an important role in the portable applications such as mobile phones, laptops and computers. They also hold good in power systems such as energy storage systems (ESS), high voltage DC (HVDC) systems and power grids. One such type of a converter used for both step-up and step-down is the single-switch buck-boost converter (SSBB) as in Fig. 1 (a). It is comprised of single switch, an inductor, a capacitor and a diode. Though the topology of SSBB is simple, it has inverting output and operates either in buck or boost mode based on the duty ratio. If the duty ratio is greater than 0.5, then the converter operates in boost mode and if the duty ratio is less than 0.5, then the converter operates in buck mode. To overcome the disadvantages of the SSBB, two-switch buck-boost (TSBB) converter was proposed as shown in Fig. 1 (b).

The conventional TSBB is the cascade of the buck and boost converters [2]. It differs SSBB by a switch and a diode. It operates in buck, boost and buck-boost mode. It is designed with less complexity and to obtain non-inverting output. The disadvantage of this converter is it has an extra switch and diode conducting in each subperiod leading to higher conduction and switching losses. In order to overcome this, a new circuit design of two-switch buck-boost converter has been proposed with lower power losses and higher efficiency [1].

The new circuit design of TSBB operates in buck, boost and buck-boost modes. It is comprised of two switch: M1 and M2, two diodes, an inductor and a capacitor as in Fig. 1 (c) Boost mode of this topology undergoes switching losses due to the switch M1 which is made on continuously. The switching losses is overcome by implementation of soft switching - zero voltage switching (ZVS) to the new circuit design of TSBB.



(a) (b) (c)

Fig.1. Circuit diagram of (a) single-switch buck-boost converter (SSBB) (b) conventional two-switch buck-boost converter (c) a new circuit design of TSBB.

The soft-switching technique is implemented to enhance the imperfect switching of the power switches by decreasing the switching losses and EMI. Zero current switching (ZCS) and zero voltage switching (ZVS) are the two types of active soft-switching techniques [5]. The ZVS or ZCS techniques drives the voltage or current of the switch to zero before the switching transition, eliminating any overlapping between voltage and current thus minimizing the losses. In this paper, ZVS is implemented to the TSBB and a comparison of the power losses with and without soft-switching is discussed in the upcoming sections.

II. OPERATION PRINCIPLES

2.1. *New circuit design of TSBB converter*

Fig. 1 (c) shows the two-switch buck-boost converter. In CCM mode, the voltage conversion ratio of this converter is

$$V_0 = \frac{d_1}{1-d_2} V_{in} \qquad (1)$$

Where d_1 and d_2 are the duty cycles of switch M1 and M2 respectively. The converter operates in buck mode when d_2 is 0 and operates in boost mode when d_1 is 1. By equation (1), we can notice that the output is non-inverting. Fig. 2 shows the modes of operation of the TSBB.

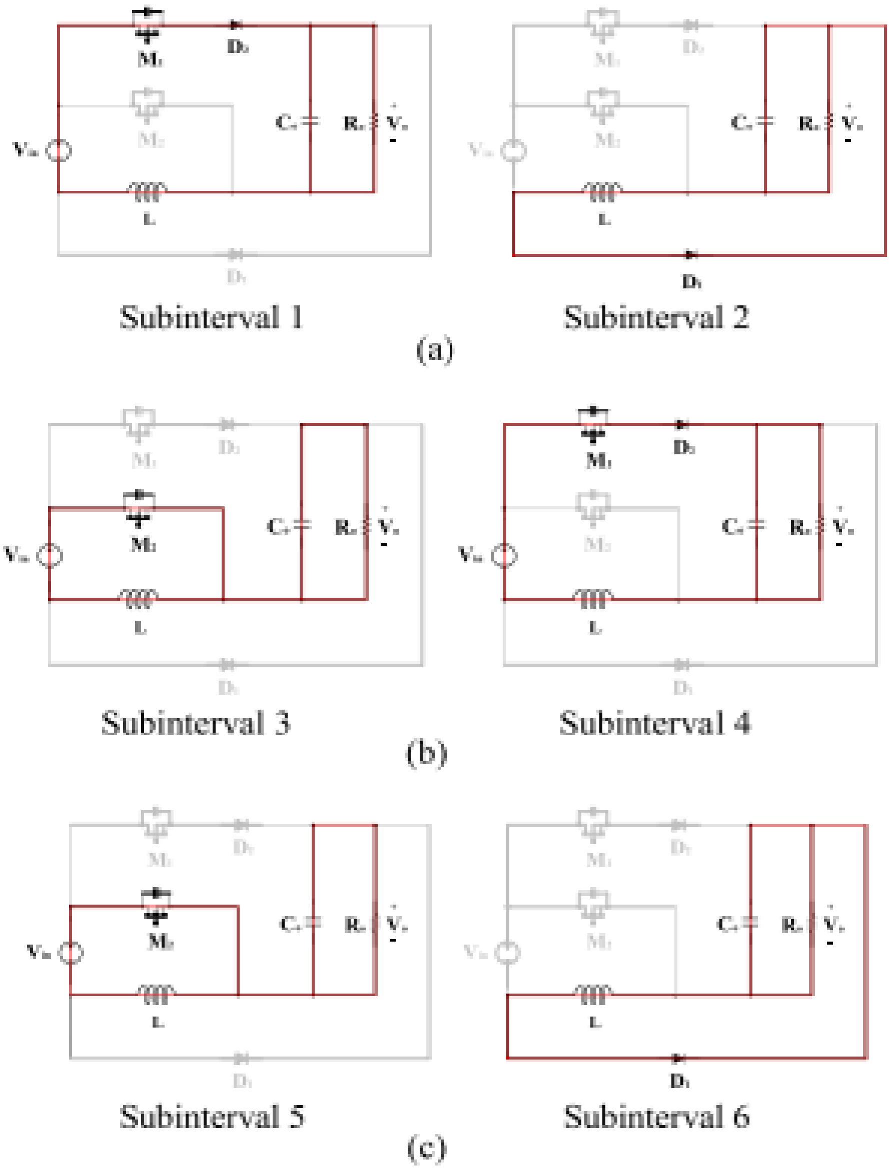


Fig. 2. Operation mode of TSBB converter. (a) Buck mode. (b) Boost mode. (c) Buck-boost mode

As shown in Fig. 2, the red lines depicts the current path. In buck mode, the switch M_1 is on whereas switch M_2 is made off. The inductor L energizes in the Subinterval 1. It dissipates energy in the Subinterval 2 when the switch M_1 is made off through the freewheeling diode D_1. In boost mode, switch M_2 is regulated and M_1 stays on during both the Subinterval: 3 and 4. When the switch M_2 stays in on state, current cannot flow through M_1 due to reverse voltage across D_2. In Subinterval 5 and Subinterval 6, the converter performs buck operation when duty ratio is less than 0.5 and boost operation when the duty ratio is greater than 0.5.

2.2. Proposed ZVS TSBB converter

The Switch M_1 remains continuously on in boost in TSBB converter which leads to continuous gate drive loss. To eliminate the switching losses, the soft-switching has been implemented. In ZVS, the voltage falls to zero before the switch transition, decreasing overlap between voltage and current thus minimizing the losses.

Fig. 3 shows the implementation of ZVS in the TSBB converter. The capacitor C_r is connected in parallel with switch M_2 in order to achieve ZVS and to limit dv/dt. The internal capacitor C_j of the switch is added with capacitor C which affects the resonant frequency thereby contributing less power dissipation in the switch. The inductor L_r is connected in series with the switch to limit di/dt surge [4]. Since L_r and C_r forms the series resonant circuit, the oscillation of L_r and C_r is initiated by turning off of the power switch.

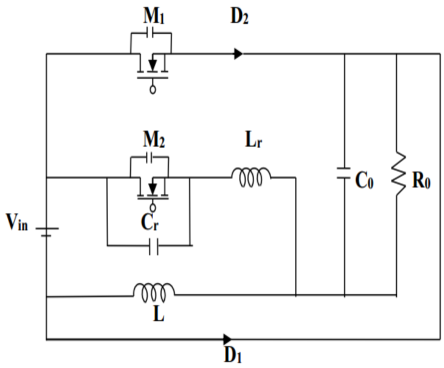


Fig. 3. ZVS two-switch buck-boost converter

2.3. Design of resonant elements

To ensure that the operation is under zero voltage- switching, the condition $Z_0 I_0 > V_s$ must hold well.

$$I_0 \frac{1}{\omega_0 C_r} > V_{in} \qquad (2)$$

$$I_0 \omega_0 L_r < V_{in} \qquad (3)$$

From equation (2), we can obtain C_r as

$$C_r < \frac{I_0}{V_{in}\omega_0} \qquad (4)$$

From equation (3), we can arrive at L_r as

$$L_r < \frac{V_{in}}{I_0 \omega_0} \qquad (5)$$

III. SIMULATION RESULTS

The operation of TSBB converter with and without ZVS has been simulated using MATLAB/Simulink. Power loss in both the conditions are calculated and compared. Fig. 4 shows the simulation circuit of the ZVS TSBB converter and Table I shows the simulation parameters used.

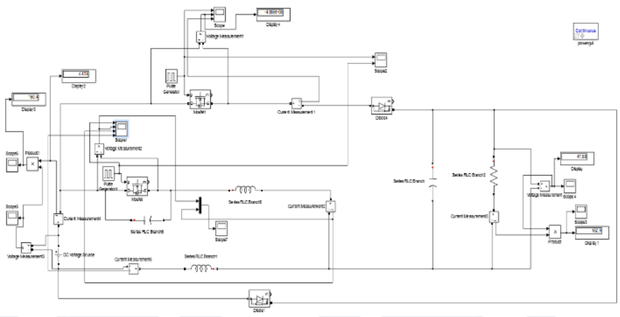
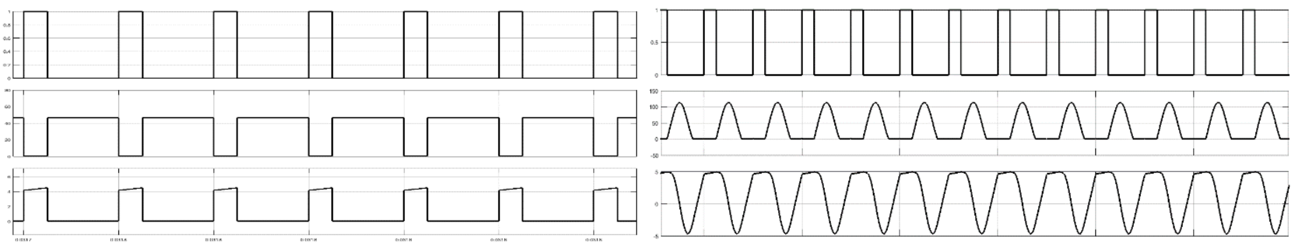


Fig. 4. Simulink circuit of a ZVS TSBB converter

Table 1 Simulation Parameters

Parameters	Values
Inductor, L	250µH
Capacitor, C	820µF
D_{boost}	0.25
$D_{buck\text{-}boost\ (boost)}$	0.57
V_{in}	36V
V_{out}	48V

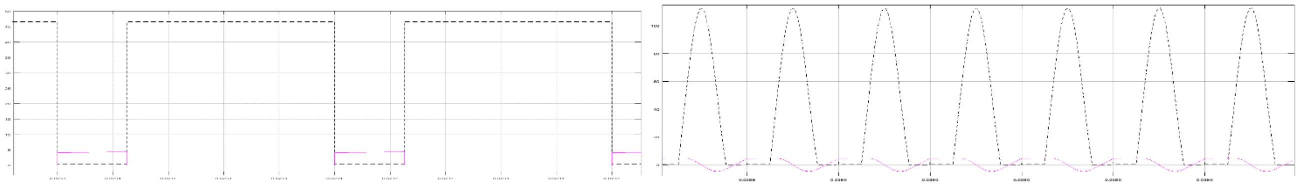
Fig. 4 shows the simulation circuit of the ZVS TSBB converter. ZVS is implemented for both the modes: boost and buck-boost (boost) mode of the TSBB converter. The resonant parameters used for the boost mode: L_r = 15µH and Cr = 0.08µF are used for the buck-boost mode: L_r = 8µH and C_r = 0.05µH are used with the frequency of 100KHz. The output voltage obtained is 48V with the load current of 3.125A.



(a) (b)

Fig. 5. Switch pulse, switch voltage and switch current waveforms of (a) TSBB converter (b) ZVS TSBB converter in boost mode

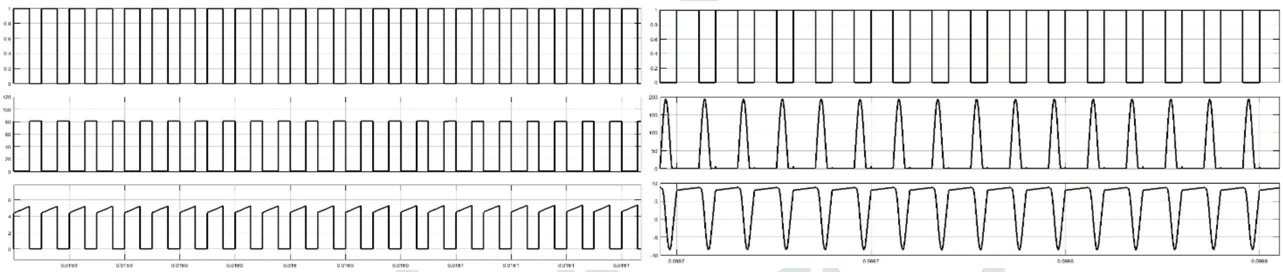
Fig. 5 shows the simulated waveforms of the switch M_2 for with and without implementation of ZVS. With the implementation of ZVS, the switch voltage tends to be zero at the transition of the switch pulse which is depicted in the Fig 5 (b). Whereas without ZVS, The voltage of 50V is obtained at the transition of the switch pulse.



(a) (b)

Fig. 6. Power MOSFET losses of switch M2 in the transient switching period of (a) TSBB converter and (b) ZVS TSBB converter in boost mode.

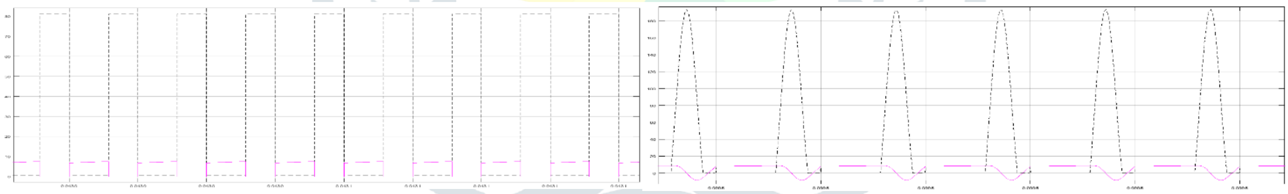
As shown in Fig. 6, the dotted lines represents the voltage and the continuous line depicts the current. The total power loss obtained without ZVS is 10.173 as in Fig. 6 (a) and total power loss obtained with ZVS is 0.70201 as in Fig. 6 (b). Comparatively, the power losses have been reduced after implementation of ZVS.



(a) (b)

Fig. 7. Switch pulse, switch voltage and switch current waveforms of (a) TSBB converter (b) ZVS TSBB converter in buck-boost (boost) mode.

Fig. 7 shows the simulated waveforms of the switch M_2 for with and without implementation of ZVS in buck-boost (boost) mode. With the implementation of ZVS, the switch voltage tends to be zero at the transition of the switch pulse which is depicted in the Fig 7 (b). Whereas without ZVS, the voltage of 80V is obtained at the transition of the switch pulse as in Fig 7 (a).



(a) (b)

Fig. 8. Power MOSFET losses of switch M2 in the transient switching period of (a) TSBB converter and (b) ZVS TSBB converter in buck-boost (boost) mode.

As shown in Fig. 8, the dotted lines represents the voltage and the continuous line depicts the current. The total power loss obtained without ZVS is 36 as in Fig. 8 (a) and total power loss obtained with ZVS is 28 as in Fig. 8 (b). Comparatively, the power losses have been reduced after implementation of ZVS.

IV. CONCLUSION

The implementation of the ZVS TSBB converter is successfully verified and presented through the MATLAB/Simulink results. The switch M_2 attains zero voltage before the switch transition in both the modes. Compared to the TSBB, the ZVS two-switch buck-boost converter reduces the switching losses in boost mode and buck-boost (boost) mode effectively.

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