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EFFICIENCY IMPROVEMENT OF DC-DC HYBRID BOOST CONVERTER BY USING SOFT SWITCHING

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Abstract- The hybrid DC-DC boost converter, which provides higher voltage at the output compared to the classical single-switch type, has a higher voltage gain. This study introduces a soft-switched DC-DC hybrid boost converter. Zero-Voltage-Transition (ZVT) soft switching method is applied to the hybrid DC-DC boost converter by adding an active circuit to reduce the switching losses of the switches. This is done by adding aa auxiliary switch. The recommended soft switching method ensures that the main switch is switched on with zero voltage switching. All semiconductors in the circuit make a smooth transition through this smooth transition, there is no additional current and voltage stress on the semiconductors. For the proposed converter, working principles and design considerations are illustrated during a single switching period. A simulation model of the proposed circuit is simulated via Orcad-PSpice program and some simulation results are obtained for the 400 W output power. The simulation results show that the proposed soft-switched hybrid converter can be operated efficiently at different load levels under soft switching process.

Keywords: Hybrid Boost, Boost, Soft-Switching, ZVT, Zero-Voltage-Transition.

I. INTRODUCTION

Many electrical devices used in homes and industries include DC-DC power converters [1]. Isolated and non-insulated types of these converters have been the subject of research for many years. [2]. Boost type DC-DC converters are the most popular among these topologies. The main advantages of the boost converter are simple control reliability, low current harmonics and high-power factor [3]. Since conventional DC-DC converters have many fields of application, these converters are required to have high efficiency. The main reason for reducing the efficiency in these converters is the semiconductor switching losses used in the circuit. [4]. There are a lot of boost type converters which have been proposed in the literature in multi-level and multi-stage to achieve high output voltages. Although these types of circuits can achieve the desired voltage results, such circuits have disadvantages that seem remote from the application.

For example, in such circuits, efficiency is low and complex structure is encountered. Another disadvantage is the backlash at the outlet [5]. In addition, to achieve higher voltage gains, many boost types are proposed in the literature, such as cascade-type, quadratic-type, multilevel-type and multi-phase type. Although a higher boost voltage gain can be obtained with such converters, they all come with disadvantages that hinder their applicability. It can also be obtained by using a two-stage "cascade and super-riser topology" structure, which is also proposed. [6], these structures result in a significantly lower efficiency and a much more complex system. Also, the other disadvantage of these topologies is the inversion of the output diodes. Dual inductor type converters are proposed to achieve higher boost voltage gain. [7], but the induced energy circulation and high voltage due to EMI are fundamental problems for these topologies. Multi-level DC-DC converters [8] and multi-phase backup converter types [9] have also been proposed for commercial or industrial applications which need higher voltage gain. The circuit complexity of these types is more than that of the classical types.

Today, semiconductor losses of converter devices developed in power electronics are popular topics. One method of reducing these losses is to run the converter at low frequencies. However, high switching is unavoidable as the circuit size increases at low frequencies. It is also an important criterion for designing a high-power density converter that make switching at high frequencies. This results in higher switching losses as well as higher EMI noise. The power of the converters and the switching losses also affect the power density as well as the efficiency. If losses are reduced, this efficiency and power density also increases.

Active and passive types of soft switching techniques are used to reduce switching losses and current and voltage stresses at high current and voltage levels. Soft switching methods can be separated into two groups as passive soft switching and active soft switching. Passive soft switching methods include passive circuit elements except for basic circuit elements, such as inductors and capacitors. Since passive soft switching techniques do not require any active switches, the design of such circuits is quite simple.

These bulky switches have relatively high stresses. The serious voltage and current stresses on the switches due to the passive method results in lower power range. Because of the disadvantages, the passive soft switching methods are less preferred. In addition, active approaches in the literature, which require a large and voluminous inductor in the auxiliary circuit of this circuit, increase the converter efficiency. In active soft switching methods, an auxiliary circuit is usually used to provide soft switching, except for basic circuit elements. This circuit includes one or more active switches, as well as passive circuit elements such as inductors and capacitors. Since soft switching provides active switches used in auxiliary circuits, the inductor and/or capacitor used in Active Auxiliary circuits are very small. Therefore, Active Auxiliary circuits, such as passive auxiliary circuits, do not increase the size of the converter.

The topology presented in [10] is an active soft switching method and the zero-voltage transient is obtained without any additional current-voltage stresses. The auxiliary switch used in this converter operates with a triggering mode which causes a greater amount of EMI and less total efficiency. The reference and auxiliary switches used in [11] are soft-switched, although there are high current peaks in the auxiliary switch.

Although there are many studies in the literature that have been made with active soft switching in DC-DC converters [12], the amount of work using active soft switching circuitry is very small topology [13] which are confirmed experimental study. The auxiliary switch of the cascade circuit shown in the reference causes the complexity of the drive circuit when it does not operate in a common mode with the master switch. The master and auxiliary switches of the summing topology operate under ZVS [14]. The use of switches requires the use of a complex driver circuit.

The need for an additional control circuit and the change in the design of the drive circuit for the auxiliary switch is the main disadvantage of active soft switching methods. The additional control circuitry and driver used for the auxiliary switch lead to increased cost and control complexity. These are the most important issues to consider for active soft switching methods.

Considering the studies related to soft-switched DC-DC converters, we propose a soft-switched DC-DC hybrid boost converter with active soft switching cell and it has a high conversion rate. Only one switch is used to obtain high voltage during the upgrade process. Also, the main power switch and the output diode in this work are set to operate in a soft switching mode. In addition to the basic semiconductors of the DC-DC hybrid boost circuit, the auxiliary switch for the auxiliary circuit is also switched by soft switching. Simulation results obtained by Orcad PSpice program have been observed and evaluated after the working principle of the proposed circuit has transferred.

II. THE PROPOSED CIRCUIT ANALYSIS

The proposed soft-switched DC-DC hybrid boost converter is shown in Figure 1. It is seen that the active soft-switching is applied by using an auxiliary switch, two auxiliary diodes, a snubber inductor and capacitor.

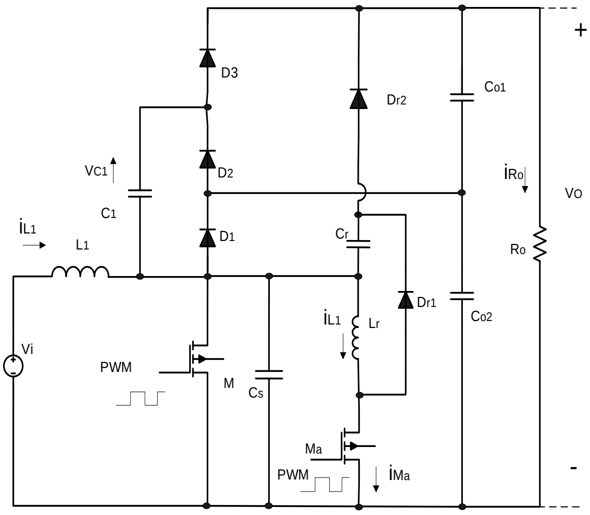

Figure 1. The proposed soft-switched DC-DC hybrid boost converter

As it is stated before, the proposed soft-switched DC-DC hybrid boost converter consists of main hybrid circuit and active auxiliary circuit. While the circuit main elements are L_1, C_1, D_1, D_2, D_3, C_{o1} and M, the auxiliary circuit elements are C_r, L_r, D_{r1}, D_{r2} and M_a (Figure 1).

The related theoretical waveforms of the proposed soft-switched DC-DC hybrid boost converter are given in Figure 2. It is seen that before t_0, main switch M and auxiliary switch M_a are off-state and the power diodes D_1 and D_3 are on-state. At t_0, when a switching turn-on signal is sent to the auxiliary power switch M_a of the proposed soft-switched DC-DC hybrid boost converter, D_2 will goes to on-state and D_1, D_o will go to off-state.

The currents through L_1 and L_2 are linearly increase and the voltage at C_1 and C_o decrease. In addition, when the M_a auxiliary circuit switch is placed on, the resonant current will begin to rise on the L_r. Since the M_a auxiliary circuit switch is limited to the current increment ratio $(di/dt)L_r$ inductor, the M_a is transmitted with a soft switch and the power output diode (D_1 and D_3) flows linearly. Therefore, the reverse recovery loss caused by the reverse flow of D_1 and D_3 diode is largely eliminated. This operation of the auxiliary switch cause ZVT for the main switch of the proposed topology. The auxiliary switch is turned off while the main switch is turned on. Before turning on the main switch there is a time interval. For the time interval ($t_1<t<t_2$), the currents through D_1 and D_3 are zero. The C_s capacitor begins to discharge and the L_r current continues to increase due to the resonance between L_r and C_s. The C_s is discharged until the voltage on it is zero (up to t_2).

After turning on the main switch, the auxiliary switch is turned off with soft switching. At this time the current through L_1 is flow on the main switch and also D_1 and D_3 will be on-state, D_2 will be off-state. The currents through L_1 decreases linearly and the voltages on output capacitor increases during turn-off the main switch. In the on-time interval of the main switch, the M main switch carries the input current. The auxiliary circuit capacitor (C_r) starts to fill and the current on the L_r starts to decrease until the end of this time period.

The C_r capacitor limits the increase in the auxiliary switch voltage over time. For this reason, the M_a switch is inserted into the segment with a soft switch. A resonance between L_r-D_3-C_r starts and the accumulated energy in L_r is transferred to the C_r capacitor.

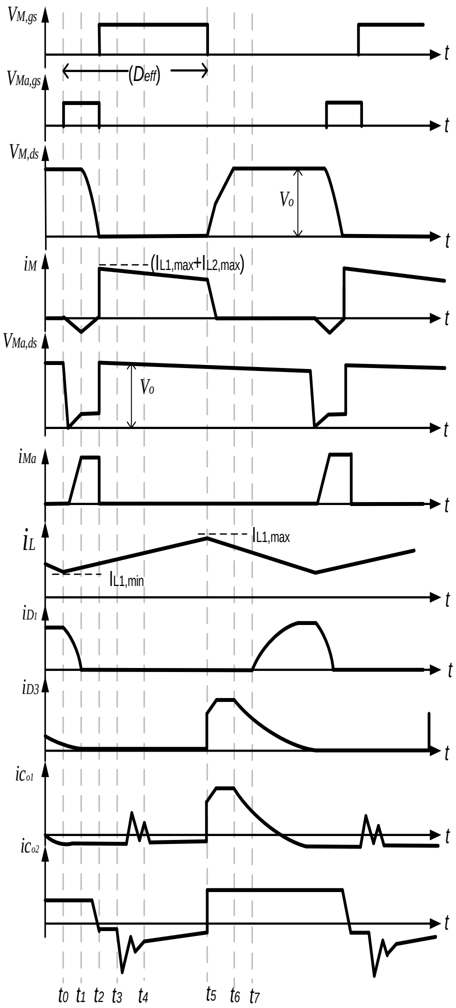

Figure 2. Theoretical waveforms of the proposed topology

The voltage conversion ratio (V_o/V_{in}) of the hybrid boost topology can be expressed in terms of duty cycle of the converter (d) and the cell number for each conversion section (N) [2]. However, the voltage conversion ratio (V_o/V_{in}) of the proposed soft-switched DC-DC hybrid boost converter can be expressed as below in terms of effective duty cycle (D_{eff}) which is sum of the duty cycle of the main switch and the switching on time of the auxiliary switch.

$$\frac{V_o}{V_{in}}=\frac{N+1}{1-D_{eff}} \tag{1}$$

There is an advantage of operating the converter in the continuous conduction mode (CCM) to reduce ripple of input inductor. Similar to the conventional boost converter, by using the inductor voltage during one stage, the inductor current ripple Δi_L can be obtained in terms of L, d and V_i as given below.

$$L=\frac{V_i D_{eff}}{\Delta i_L\, f_s} \tag{2}$$

$$\Delta i_L=\frac{V_i D_{eff}}{L.f_s} \tag{3}$$

where, f_s is the switching frequency and by using Equation (1), we easily obtain inductor value as given in Equation (4).

$$L=\frac{V_o.\left(1-D_{eff}\right)}{\Delta i_L\, f_s.\left(N+1\right)} \tag{4}$$

The output capacitance should be designed to reduce output voltage ripple content and it uses the same methodology as the conventional boost converter. The individual capacitance values can be calculated by multiplying number of series output capacitors. The capacitor value which determines output voltage ripple is important when designing a converter. The larger capacitor value decreases output voltage ripple, while it results in a bulky converter. Therefore, output capacitor value is selected according to these considerations.

III. SIMULATION RESULTS

The proposed soft-switched DC-DC hybrid boost converter has been simulated via Orcad/PSpice by using the parameters given in Table 1. Simulation results are observed to validate the theoretical waveforms.

Table 1. The components/parameters used in the simulation

Parameters	Value
Output power (P_o)	400 W
Input voltage (V_{in})	50 V
Output voltage (V_o)	240 V
Switching frequency (f_s)	50 kHz
Inductor (L_1)	0.9 mH
Capacitor (C_1)	25 uF
Output capacitor (C_{o1}, C_{o2})	220 uF
Main and Auxiliary switches, (M, M_a)	IRFP460
Diodes, D_1, D_2, D_3	IXYS DSEP 29-12 A
Auxiliary circuit inductor (L_r)	2.5 uH
Auxiliary circuit capacitor (C_r)	5 nF
Auxiliary circuit capacitor (C_s)	1.1 nF

A classical voltage controller is applied to the proposed soft-switched DC-DC hybrid boost converter to obtain 240 V at the output while the input voltage is 50V. As seen from Figute 3, the desired output voltage can be obtained with lower voltage ripple. It is seen that the output voltage reaches the steady-state value with a transient ripple which is the nature of the characteristics of the transfer function related to the circuit.

The applied switching signals of the main and auxiliary switches at any time are given in Figure 4 which shows us the auxiliary switch is operated for a short time and after it the on-time signal is applied to the main switch. The on-time period of the auxiliary switch is nearly 5% of the switching period. This time interval can be calculated according to auxiliary circuit parameters and the main circuit parameters. As it is seen, there is a reverse small ripple in the gate signal of the main switch at the beginning of on-time. This is due to driver circuit and parasitic capacitors of the main switch.

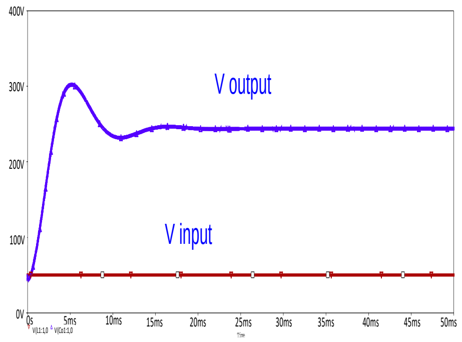

Figure 3. Output voltage (V_{out}) and input voltage (V_{in})

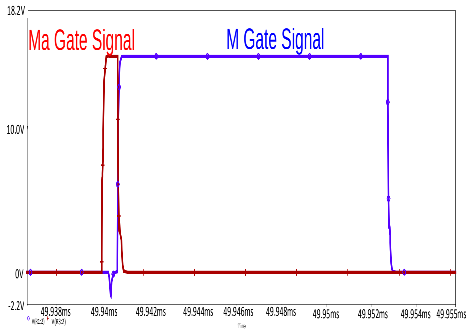

Figure 4. Gate signal of main switch M and auxiliary switch M_a

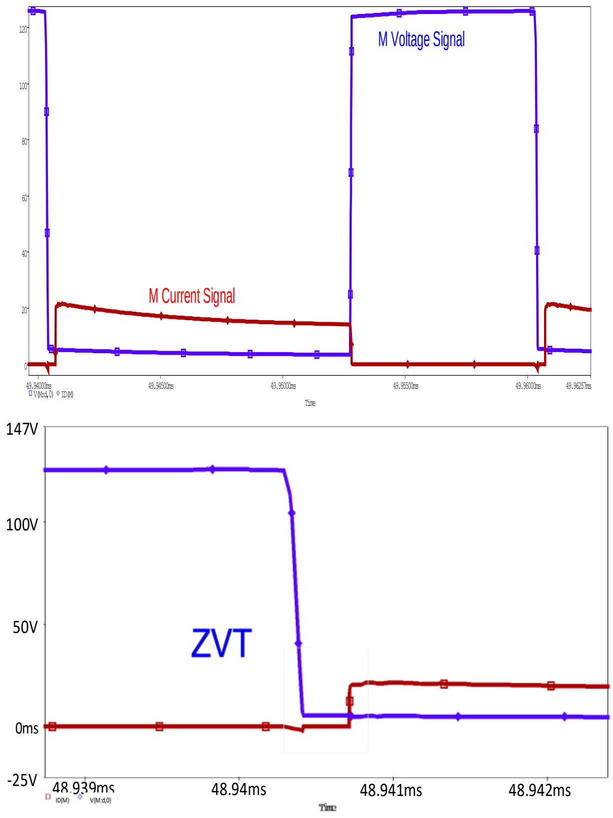

Figure 5. Simulations results of the voltage-current of the main switch, M

The voltage-current waveforms of the main switch are given in Figure 5 for a switching period and for on-time interval respectively. As seen from the related figures, after turning on the main switch, the auxiliary switch is turned off with soft switching. In the on-time interval of the main switch, the M main switch carries the input current. Before the turning-on the main switch, the resonance between L_r-D_3-C_r starts and the accumulated energy in L_r is transferred to the C_r capacitor. Therefore, the main switch is operated at ZVT during on-state. Also, the auxiliary switch is operated in ZVS.

The voltage and current waveforms of the auxiliary switch are given in Figure 6 for a switching period. Figure 6 shows that the auxiliary switch is soft-switched at on-time and off-time. When a turn-on signal is sent to the auxiliary power switch M_a of the proposed converter, the resonant current will begin to rise on the L_r. Since the M_a auxiliary circuit switch is limited to the current increment ratio $(di/dt)L_r$ inductor, the M_a is transmitted with a soft switch and the power output diode (D_1 and D_3) flows linearly. Therefore, the reverse recovery loss caused by the reverse flow of D_1 and D_3 diode is largely eliminated. This operation causes the operation of the auxiliary switch in ZVS.

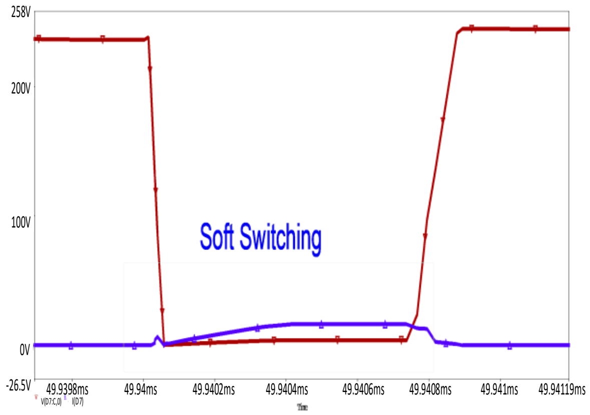

Figure 6. Simulations results of the voltage-current of auxiliary switch

IV. CONCLUSIONS

This paper introduces the analysis and simulation results of an active soft-switched hybrid DC-DC boost converter. The proposed soft-switched hybrid DC-DC boost converter has a larger switching ratio and less switching losses than conventional boost converters. An auxiliary switch is switched on and off under soft switching, while the main switch is operated under ZVT during on-state. Also, the diodes used in the proposed converter are operated without voltage and current stresses. The validation of the theoretical results has been confirmed by simulation results.

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BIOGRAPHIES

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