New Active Snubber Cells for High Step-up Interleaved DC-DC Converters

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ABSTRACT

This paper proposes a new pair of Active Snubber Cells (ASCs) which can fully provide soft switching for a Floating-output Double Boost Converter (FDBC). Besides that, the introduced ASCs are applicable for all basic DC-DC converters. Main switches of the FDBC turn on and off with ZVS. However, the main diodes are ZCS turned off. Furthermore Snubber switches are turned on and off with ZCS and ZVS respectively. It worthy to mention also that the soft switching for snubber diodes of the presented cells is achieved. A 1.5kW, 100kHz prototype of the FDBC with the proposed ASCs was built and evaluated; and the maximum attained efficiency is 97.3%.

1. Introduction

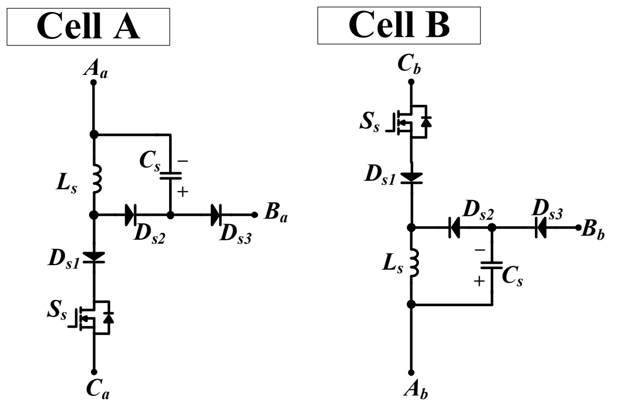
In Fuel Cells (FCs) or Photovoltaics (PVs) application, step-up DC-DC converter is needed to boost the low output voltage of FCs or PVs to higher level [1]-[5]. The Interleaved Boost Converter (IBC) were used in [3]-[5]. Even though the IBC have a simple structure and can reduce input current ripple, the IBC have two main drawbacks: 1) The practically realizable voltage gain of Conventional Boost Converter (CBC) is limited by the component parasitic elements, which increases the actual duty cycle; 2) Switching frequency is limited because of hard switching operation. Thus, the filter size increases and the dynamic performance decreases. With the mentioned issues, a converter that achieves higher voltage gain and operates with soft switching should be used. Among the high voltage gain DC-DC converters that have been proposed [6]-[8], the FDBC has high voltage gain, low input current ripple and simple structure. The drawback of the FDBC is all of the semiconductor devices operate with hard switching. Accordingly, a soft switching technique is needed to increase the switching frequency of the FDBC.

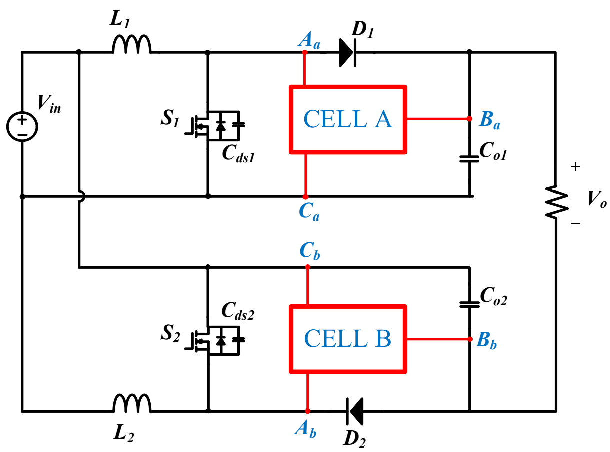
In the literature, there are many soft switching techniques were proposed by employing a snubber cell [9]-[13]. The snubber cells can be classified as passive [9], [10] and active snubber [11]-[13]. Even though the passive snubber circuits have advantage of using only passive components, it can not completely eliminate the turn on loss of the switch. This issue reduce the beneficial effect of using snubber cell especially when mosfet is use as the main switch. In addition, the circuit topology with passive snubber is complicated and difficult to analyze. Therefore, an Active Snubber Cell (ACS) becomes more favorable method. Even though it uses an active switch, but the ASC only works at a little fraction for a whole operating period. In addition, ASC only consumes a little amount of power, which result in a small portion of the whole converter volume.

In this paper, a new pair of ASCs which can provide fully soft switching for FDBC is proposed. Furthermore, the proposed ASCs can be applied for interleaved converter as well as for all of the basic DC-DC converters.

2. Proposed ASCs

There are two ASCs with the same features are proposed in this paper as shown in Fig. 1. Each ASC consists of one auxiliary switch, three diodes, one inductor, and one capacitor as shown in Fig. 1. The selection of cell depends on the applied converter. With the conventional Boost, Cúk or Sepic converter, cell A is used. Cell B is selected for Buck, Buck Boost, Zeta or floating Boost converter. As the aforementioned, the integration of the proposed ASCs into the FDBC is shown in Fig. 2. In which, Cell A is used for the boost converter while Cell B is used for the floating boost





converter. Both converters with the integration of ASCs have the same operating principle. Therefore, in order to make the paper simple, boost converter with the proposed ASC which is shown in Fig. 3 will be analyzed.

The key waveforms concerning to the operation modes is shown in Fig. 4. Snubber switch S_s is turned on within a short period t_{Ss} prior to S_1, and then turned off at the same time with main switch turns on. In order to provide ZVS turn on for main switch, the snubber inductor current is required to reach input inductor current and discharge all the energy stored in parasitic capacitor of the main switch during t_{Ss}. The current slope during turning on of the snubber switch and turning off of the main diode is determined in (1).

$$\frac{d_i}{dt} = \frac{V_o}{L_s} \tag{1}$$

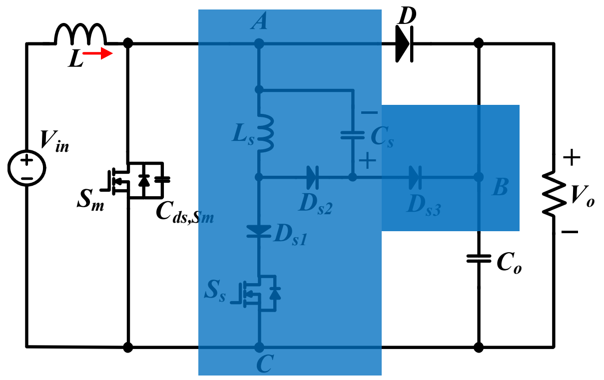


Fig. 3. Integration of Cell A into boost converter

$$i_{Ls,peak} = I_{in} + V_o\sqrt{\frac{C_{ds,m}}{L_s}} \tag{2}$$

After that, main switch turns on and snubber switch turns off, diode D_{S2} is turned on to conduct the snubber inductor current to charge the snubber capacitor voltage up to output voltage which represents the turn off voltage of the snubber switch as shown in equation (3), the snubber switch is therefore turned off with ZVS.

$$V_{Ss} = V_{Cs} = i_{Ls,peak}\sqrt{\frac{L_s}{C_s}}\sin[\omega(t-t_4)] \tag{3}$$

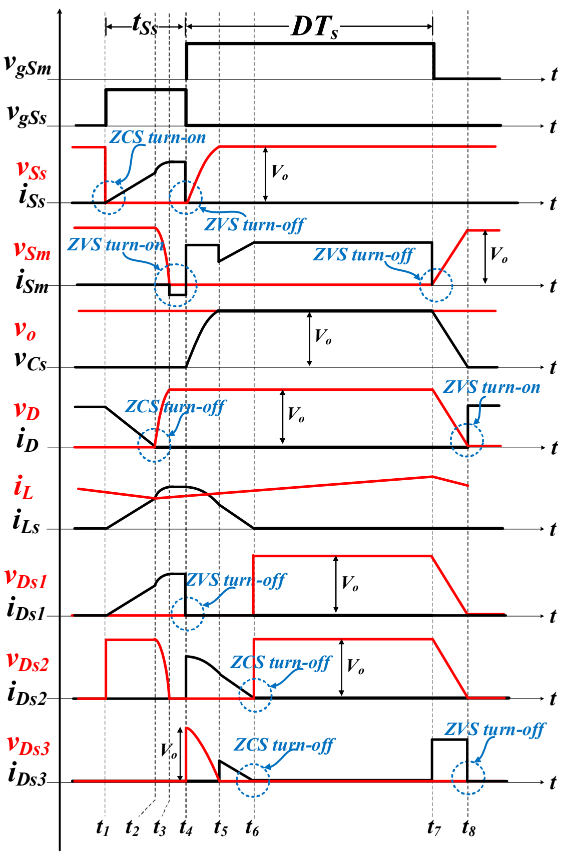


Fig. 4. Key waveforms concerning to the operation modes

Where:
$$\omega = \frac{1}{\sqrt{L_s C_s}} \tag{4}$$

After snubber capacitor reach to V_o, diode D_{s3} turns on to transfer rest of the energy from snubber inductor to output. Then, the snubber circuit is off and the converter operated as normal on state until main switch turns off.

Before main switch turn off, main diode is reverse bias cause by the snubber capacitor voltage, which has the value of V_o at this moment. Therefore, after main switch turning off, most of the input current is used to discharge the snubber capacitor resulting in achieving ZVS turn off in main switch. The formula for this step is as following:

$$V_{Sm} = V_o - V_{Cs} = \frac{I_{in}}{C_s + C_{ds,m}}(t - t_7) \tag{5}$$

The role of the snubber circuit ends when the capacitor C_s is fully discharged; then main diode is turned on during the last mode of operation.

3. Experimental results

A 1.5 kW prototype of the circuit as shown in Fig. 2 has been built. The specification and design parameters are as following:

• P_o = 1.5 kW • V_o = 400 V • V_{in} = 100 V • f_S = 100 kHz • t_{Ss} = 800 ns
• L_s = 15 μH • C_s = 6.8 nF • $C_{o1} = C_{o2}$ = 30 μF • $L_1 = L_2$ = 500 μH

The power rating of the components which were gotten form simulated

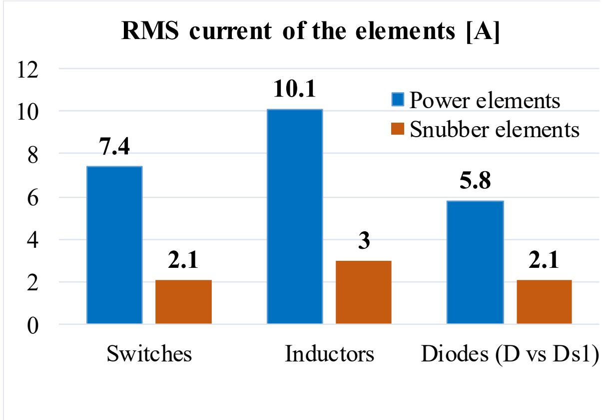


Fig. 5. Currents rating of the elements

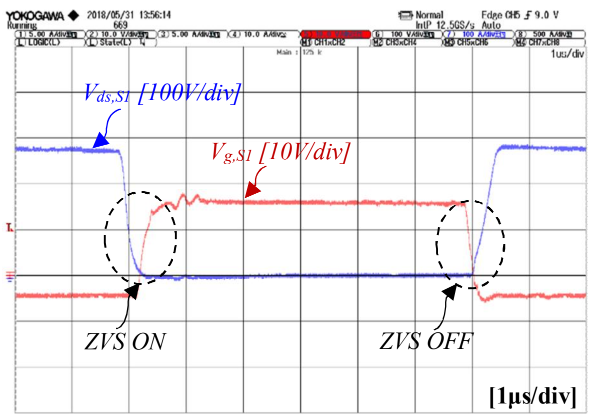


Fig. 6. ZVS turn on and off of main switch

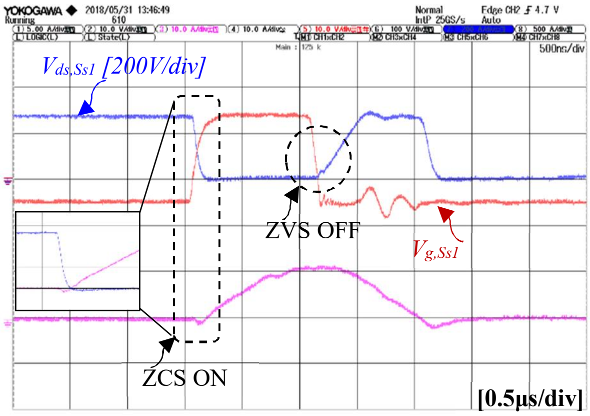


Fig. 7. ZCS turn on and ZVS turn OFF of snubber switch

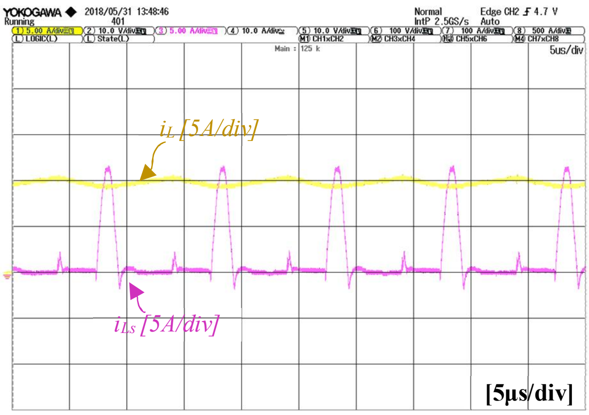


Fig. 8. Measured efficiency of the converter

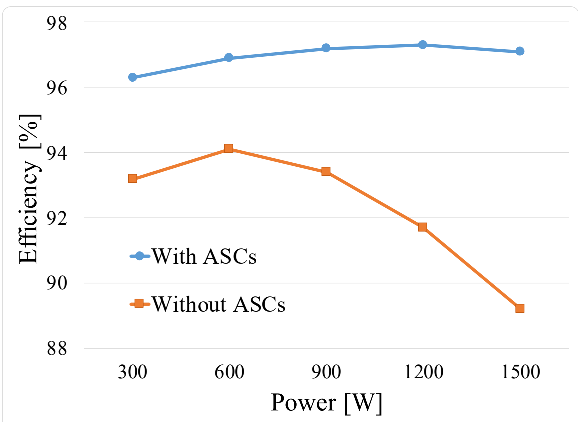


Fig. 9. Measured efficiency of the converter

results are shown in Fig. 5. As illustrated in Fig. 5, the power rating of each snubber element is significantly small in comparison with power rating of the main elements.

Main switch achieves ZVS turn on and off is shown in Fig. 6. The soft switching characteristic of the snubber switch is shown in Fig. 7. In which, the ZCS turn on current of the snubber switch is represented by the snubber inductor current.

The input current and snubber inductor current are shown in Fig. 8.

The efficiency of the FDBC with the proposed ASCs, which reached its maximum value (97.3%) at 1.2kW, is measured by YOKOGAWA WT3000 and given in Fig. 9.

4. Conclusions

A pair of ASCs applied in FDBC that reduces the switching loss are presented. The proposed ASCs can fully provide soft switching for not only FDBC but also for all the basic DC-DC converters. The 1.5kW, 100kHz prototype of FDBC with 100V input and 400V output has been built to verify the theoretical analysis. The experiment achieved maximum efficiency as 97.3% at 1.2kW. The experimental results with full load will be shown in the later version of the paper.

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