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Soft Switching PWM Isolated Boost Converter for Fuel cell Application

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Abstract

In this paper a new soft switching isolated boost type converter is introduced for fuel cell applications. In this converter zero voltage switching condition is achieved for the main switches and the auxiliary circuit is also soft switched. Also, the converter control circuit is simple PWM. Due to achieved soft switching condition, the converter can operate at high powers which make it suitable for fuel cell applications. Also, due to high voltage gain of the converter and isolation between input and output sources, the converter is a proper choice for the interface of fuel cell and inverters. Furthermore, the input current of the converter (current drained from the fuel cell) is almost constant since it is a boost type converter. The converter is analyzed and the simulation results presented confirm the validity of theoretical analysis.

1 Introduction

Boost type converters are vastly used as the interface circuit for solar cells, batteries and fuel cell since their input current is almost constant. Also boost type isolated converters can provide high voltage gain because in these converters the total converter gain is the multiply of boost stage gain and transformer voltage gain. Therefore, these converters are suitable solutions to boost the low output voltage of solar cells, batteries and fuel cells to provide high DC voltage for the inverter stage.

In isolated boost converters usually high voltage stress and high switching losses are applied to the switches due to converter leakage inductance. Therefore, the efficiency of these converters considerably decreases and also due to voltage spikes on the converter switch, switches with high voltage rating should be used. RCD snubbers and clamps can be used to reduce switching losses and to limit voltage spikes across the switch. However, RCD snubbers and clamps increase the total converter loss and further reduce the converter efficiency.

Lossless snubbers are another solution to limit the voltage spikes and to reduce the switching losses and also to increase efficiency [1-8]. Several lossless snubbers are previously introduced for boost converters in [6-7]. But, in these converters additional current stress is applied on the main switches. In the converter introduced in [8], a lossless snubber is introduced for current fed converters which is applied in the secondary side of transformer. This lossless snubber can reduce switching losses, but it is unable to limit the voltage spikes across the switches. Therefore, for practical implementation, a RCD clamp is also required in the transformer primary side.

In this paper, a new soft switching boost converter is introduced which does not suffer from the above mentioned disadvantages. This converter is introduced and analyzed in the second section. Simulation results are presented in the third section using PSpice software. Therefore, the simulation results are with the actual model of semiconductor devices. Also, leakage inductance of transformers is considered for the simulation purpose to verify the effectiveness of applied soft switching auxiliary circuit.

2 Converter Analysis

The proposed converter is shown in Fig. 1. S_1 and S_2 are converter main switches and unidirectional switches S_{a1} and S_{a2} are the converter auxiliary switches. Before the first mode, it is assumed that S_1 and D_1 are conducting and all other semiconductor devices are off. Also, the transformer magnetizing inductance current, input inductor current and capacitor C voltage can be assumed constant and equal I_m, I_{in} and V_c, respectively. According to Fig. 1 the converter main transformer turns ratio is 1:n and coupled inductors L_{a1}, L_{a2} and L_{a3} turns ratio is 1:1:m.

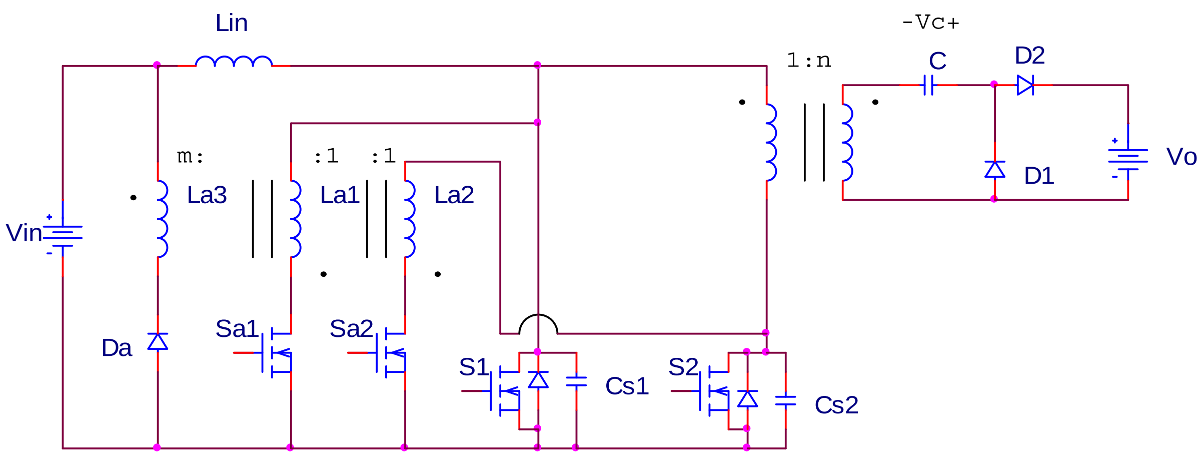

Figure 1: Proposed soft switching isolated boost converter.

Assuming all semiconductor devices ideal, the converter operating modes are as following:

Mode 1: By turning the S_{a2} on, this mode begins. By turning this switch on, V_c/n is placed across L_{a2} and its current increases linearly to I_m and S_1 current decreases to I_{in}-I_m. Thus, S_{a2} turn on is zero current switching.

Mode 2: In this mode a resonance starts between C_{s2} and L_{a2} and C_{s2} completely discharges. L_{a2} current during this mode and at the end of this mode are:

$$I_{La2} = I_m + \frac{V_C}{nZ_2}\sin(\omega_2(t)) \tag{1}$$

$$I_{La2} = I_m + \frac{V_C}{nZ_2} = I_2 \tag{2}$$

where:

$$\omega_2 = \frac{1}{\sqrt{L_{a2}C_{S2}}} \tag{3}$$

$$Z_2 = \sqrt{\frac{L_{a2}}{C_{S2}}} \tag{4}$$

Mode 3: L_{a2} current runs through the body diode of S_2. S_2 can be turned on under zero voltage switching. L_{a2} current remains constant until S_{a2} is turned off.

Mode 4: S_1 is turned off and the difference of input inductor current and I_m charges C_{s1} up to $(V_0-V_c)/n$. Thus, S_1 turn off is under zero voltage switching. C_{s1} voltage equation during this mode is:

$$V_{C_{S1}} = \frac{(I_{in} - I_m).t}{C_{S1}} \tag{5}$$

Mode 5: The difference of input current and L_{a2} current runs through S_2.

Mode 6: S_{a2} is turned off and L_{a2} current runs through L_{a3} and D_a. Thus, the voltage across S_{a2} is equal $V_{in}/_m$. By selecting relatively large value for m, S_{a2} turns off under almost zero voltage switching. At the end of this mode D_a current becomes zero. L_{a3} current at the beginning of this mode is I_2/m. Thus, L_{a3} current equation during this mode is:

$$I_{La3} = \frac{I_2}{m} - \frac{V_{in}t}{L_{a3}} \tag{6}$$

Mode 7: In this mode I_{in} runs through S_2. Also D_2 is conducting in this mode.

Mode 8: This mode begins by turning S_{a1} on. Thus, $(V_0-V_c)/n$ is placed across and L_{a1} current linearly increases to $I_{in}-I_m$ and S_2 current decreases to I_m.

Mode 9: In this mode, C_{s1} discharges in a resonance with L_{a1}. Thus, L_{a1} current equation during this mode and its value at the end of this mode are:

$$I_{La1} = I_m + \frac{V_0 - V_C}{nZ_1}\sin(\omega_1(t)) \tag{7}$$

$$I_{La1} = I_m + \frac{V_0 - V_C}{nZ_1} = \frac{I_1}{m} \tag{8}$$

where:

$$\omega_1 = \frac{1}{\sqrt{L_{a1}C_{S1}}} \tag{9}$$

$$Z_2 = \sqrt{\frac{L_{a1}}{C_{S1}}} \tag{10}$$

Mode 10: In this mode L_{a1} current is constant and runs through body diode of S_1. During this mode S_1 can be turned on under zero voltage switching. L_{a1} current remains constant until S_{a1} is turned off.

Mode 11: This mode starts by turning S_2 off and C_{s1} is charged up to V_c/n with constant current I_m. Therefore, S_2 turn off is zero voltage switching. C_{s2} voltage equation during this mode is:

$$V_{C_{S2}} = \frac{I_m.t}{C_{S2}} \tag{11}$$

Mode 12: The difference of input current and L_{a1} current runs through S_1.

Mode 13: This mode begins with turning S_{a1} off and thus, L_{a1} current runs through L_{a3}. Therefore, V_{in}/m is placed across S_{a1} and by choosing relatively large value for m, S_{a1} turn off is almost zero voltage switching. At the end of this mode D_a current becomes zero. L_{a3} current at the beginning of this mode is I_1/m. Thus, L_{a3} current equation during this mode is:

$$I_{La3} = \frac{I_1}{m} - \frac{V_{in}t}{L_{a3}} \tag{12}$$

Mode 14: In this mode S_1 and D_1 are on and all other semiconductor devices are off.

The converter theoretical waveforms are shown in Fig. 2. Since the waveforms of S_1 and S_2 and also the waveforms of S_{a1} and S_{a2} are similar, only theoretical waveforms of S_2 and S_{a2} are presented. The main converter can be designed like its hard switching counterpart [9]. Designing the auxiliary circuit of the converter is simple. C_{s1} and C_{s2} are the snubber capacitors of S_1 and S_2 and these capacitors are designed similar to any turn off snubber. Also, L_{a1} and L_{a2} are the turn on snubber off S_{a1} and S_{a2} accordingly and these inductors can be designed like any turn on snubber inductor. It is desirable to choose large value for m. However, this will result in large values of L_{a3}. Therefore, in mode 6 and 13, L_{a3} current won't reach zero before turning the auxiliary switches on again. Thus, the only limitation on m is the duration of modes 6 and 13.

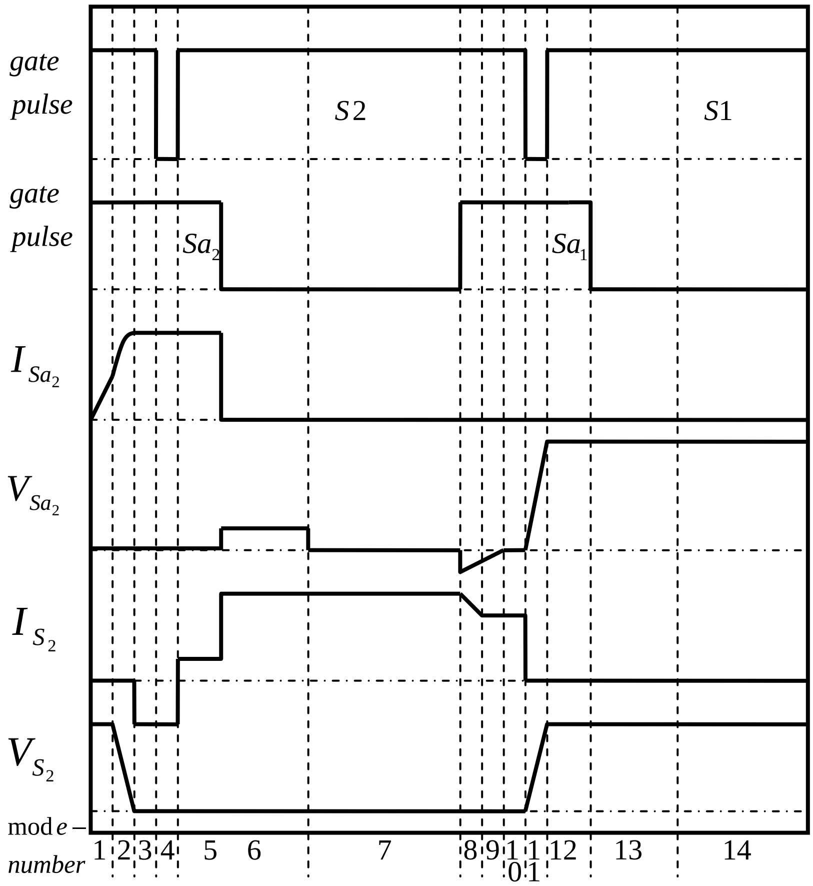

Figure 2: **Theoretical waveforms of the converter.**

3 Simulation Results

A 200 W prototype converter is simulated with PSpice software. The converter input voltage is 48 V and its output voltage is 400 V. The converter switching frequency is 100 kHz. For the converter main switches IRF740 model is used and for the converter auxiliary switches IRGBC20F model is used. The converter operating duty cycle is selected 0.5 and therefore the main converter approximately provides voltage gain of 4. Also, the converter transformer provides a voltage gain of 2.5 nF capacitors are used for C_{s1} and C_{s2}. Also, 4 uH inductors are applied for L_{a1} and L_{a2} and 100 uH inductor is also applied for L_{a3}. 1 uH inductor is added in series with the transformer for the leakage inductance. Also, 0.1 uH inductors are added in series with L_{a1} and L_{a2} for their leakage inductances. A 200 uH inductor is used for the input filter inductor and a 50 nF capacitor is used for the output filter capacitor. A 0.1 uF capacitor is used for C. MUR460 model is used for diodes. The converter simulation results are presented in Fig. 3. The simulation results confirm the validity of theoretical analysis presented. Also, it can be observed from the simulation results that snubber capacitor has limited the voltage spikes due to transformer leakage inductance which is observable in hard switching isolated DC-DC converters.

The simulation results show that the efficiency of soft switching converter is approximately 88.5% while the efficiency of hard switching counterpart is approximately 83%.

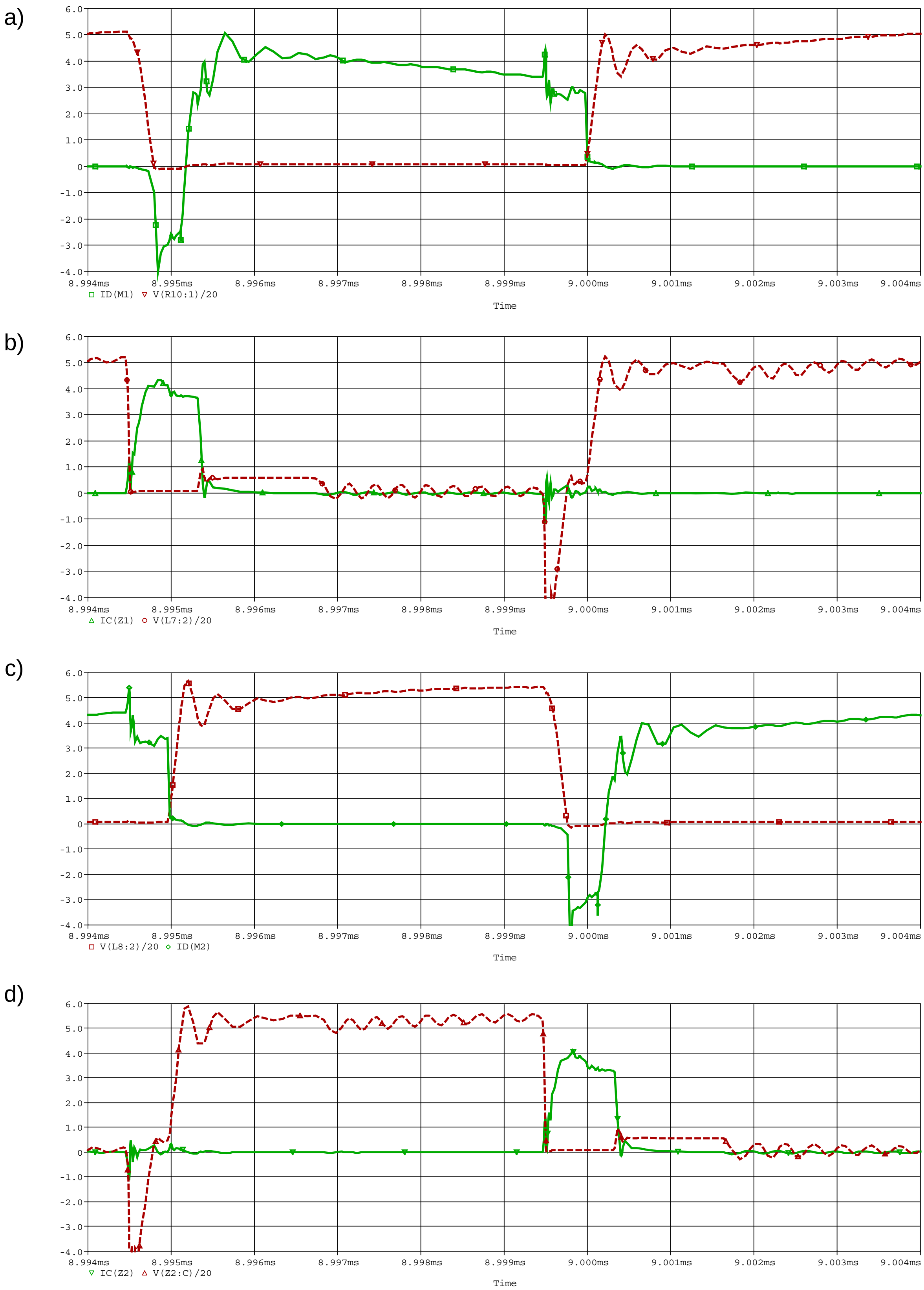

Figure 3: **Voltage (broken line) and current (continues line) of (a) S2 (b) Sa2 (c) S1 (d) Sa1. (vertical scale is 20 V/div or 5 A/div and time scale is 1 us/div).**

4 Conclusions

In this paper a soft switching boost type converter is introduced and analyzed. In this converter zero voltage switching condition is achieved for main switches. Also, the auxiliary switches are soft switched. Simulation results presented justify the theoretical analysis and the effectiveness of the introduced method.

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