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Comparative Study of Different Soft Switching Bidirectional Dc-Dc Converters

Bindhu Babu[1], Divya S[2]
[1]*(Department of EEE, ASIET Kalady, India)*
[2]*(Department of EEE, ASIET Kalady, India)*

Abstract: *Bidirectional DC-DC converters are widely used in industrial applications. High voltage conversion ratio, high efficiency and economy are challenging issues for the research and development of advanced bidirectional DC-DC converters. Various kinds of soft-switching converters are introduced here for different applications like fuel cells, super-capacitors, etc. These soft-switching methodologies can increase the switching frequency of the converter with reduced switching losses. This paper presents an analysis and comparative study of several soft switching non-isolated bi-directional DC-DC converters. Furthermore, a soft-switching circuit with an active snubber is designed and realized to reduce EMI and losses in switching devices. Here the zero-voltage-switching (ZVS) of main switches is achieved by utilizing an active snubber which consists of auxiliary switches, diodes, an inductor, and a capacitor. Although conduction losses associated with additional components increase, switching losses are significantly reduced due to the ZVS operation of main switches. Therefore, total efficiency is improved. By using an active snubber, the total amount of the current flowing through the auxiliary circuit decreases significantly since the active snubber operates during short time intervals. Therefore, conduction losses in main switches and auxiliary circuit are significantly reduced and thus overall efficiency is improved.*

Keywords: *DC-DC converters, zero-voltage-switching, active snubber*

I. Introduction

Bidirectional dc-dc convertor can perform the stepping up and stepping down of voltage level with ability of power flow in each directions. Bidirectional dc-dc converters currently are utilized in various applications like energy storage system of electrical vehicles, fuel cell, renewable energy and uninterrupted power supplies [5]. Previously they were used just for speed management and regenerative braking of motor drives. The basic purpose of using bidirectional DC-DC converter is to attain DC bus voltage regulation with ability of power flow in both directions. Conventional battery charger/discharger circuits, Figure1 consist of two converters; one for the charging the battery from a DC bus and the other to provide power to the DC bus from the battery. The proposed bi-directional converter provides both functions of battery charging and discharging in a single conversion unit with its bidirectional power flow capability [9] shown in Figure1.Bidirectional dc-dc converters control the power flow between the dc bus and the low-voltage sources such as back-up batteries, fuel cells, and super capacitor. Based on the applications bidirectional dc-dc converters are classified into isolated versions and non-isolated versions. An isolated bidirectional dc-dc converter has more than 4 switches and an isolated transformer, it has higher conduction losses and lower efficiency than a non-isolated bidirectional dc-dc converter.

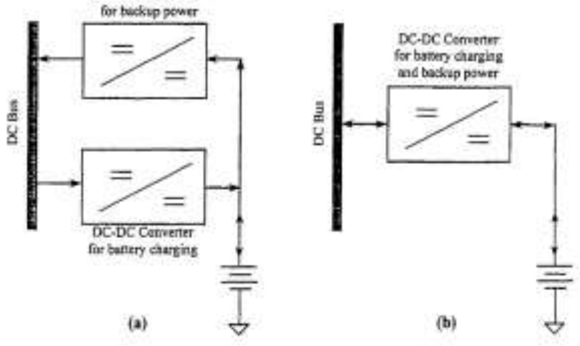

Fig.1. *Conventional circuit using two uni-directional converters. & Battery charger/discharger circuit using proposed bi-directional converter*

On the other hand, the non-isolated bidirectional dc-dc converter has high efficiency due to simple structure. Therefore, soft-switching techniques are applied to the non-isolated bidirectional dc-dc converter to achieve soft-switching of power switches in a wide range of load and reduce switching noises.

II. Soft Switching Bidirectional Dc-Dc Converters

Conventional Soft Switching Bidirectional Dc-Dc Converter

Conventional soft-switching bidirectional dc-dc converter that achieves soft switching by simply adding an auxiliary inductor and a capacitor is shown in Figure 2 [1].The main disadvantage of this converter is that large circulating current always flows through an auxiliary inductor and a capacitor for satisfying ZVS of switches, irrespective of load. So, high conduction losses are induced in the components.

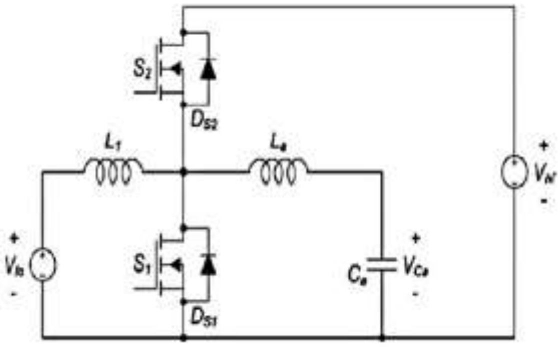

Fig.2. Conventional soft switching bidirectional dc-dc converter

In Fig.3. and Fig.4., the switch voltages Vs1 and Vs2 become zero with the turn-on of the intrinsic body diodes Ds1 and Ds2. And then, the gate Pulses Vgs1 and Vgs2 are applied to the each switch before the currents Is1 and Is2 change their directions. Therefore, ZVS of the main switches is achieved, and the switching noise can be alleviated.

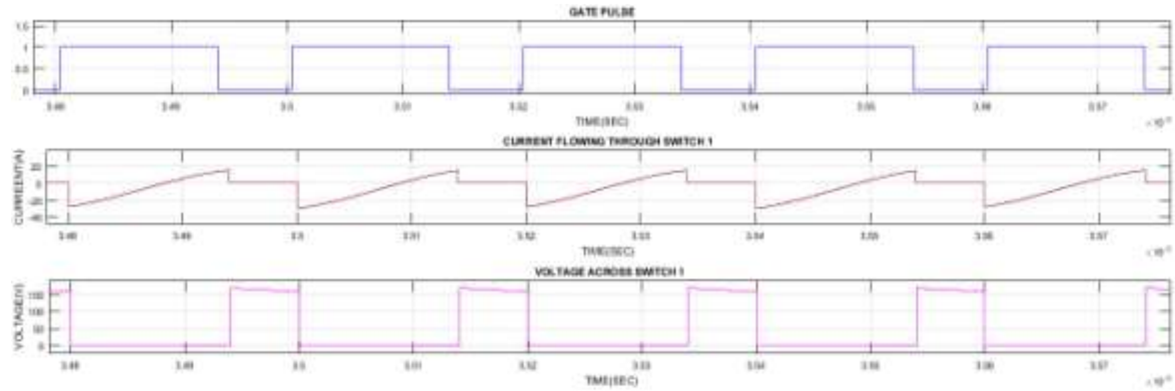

Fig.3. Simulated waveforms of Soft switching of switch 1

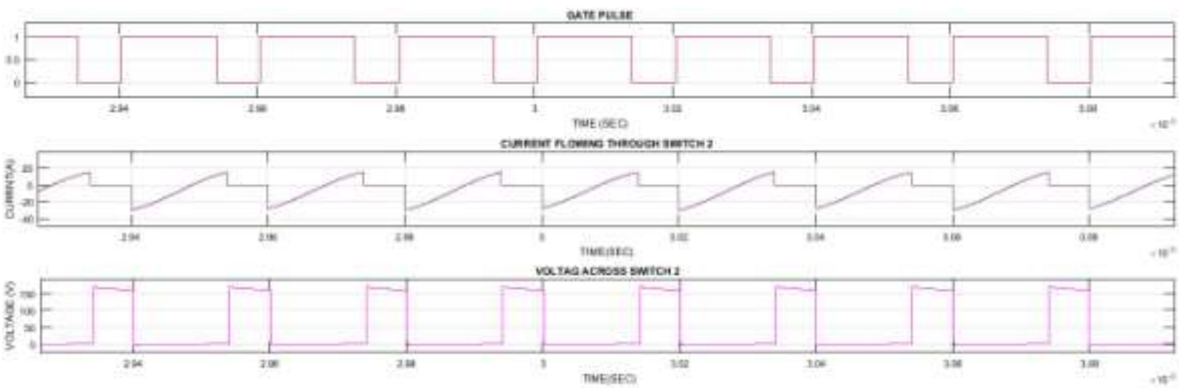

Fig.4. Simulated waveforms of Soft switching of switch 2

The waveforms of main inductor (L1) current IL1 and auxiliary inductor (L2) current IL2 during a few switching period is shown in the Fig.5

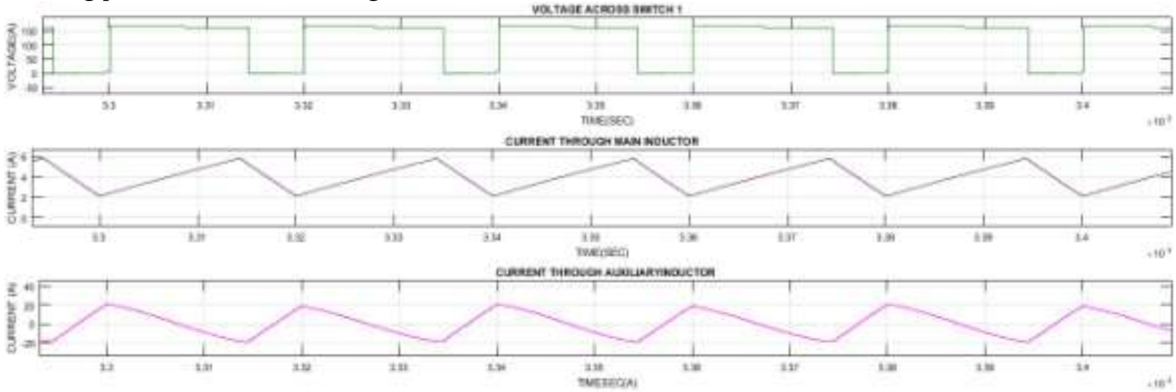

Fig.5. Simulated waveforms of VS1, IL1, IL2 in Boost mode operation

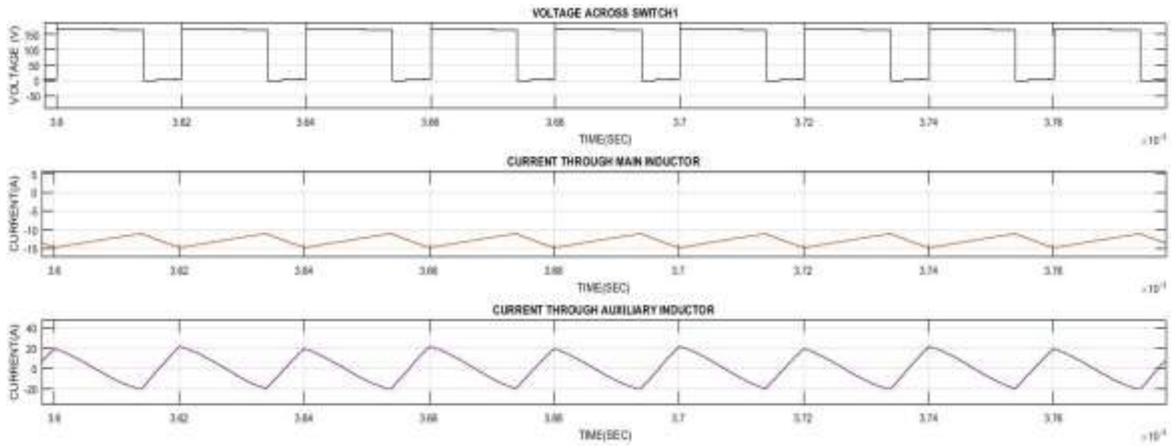

Fig.6. Simulated waveforms of VS1, IL1, IL2 in Buck mode operation

In this converter, large circulating current always flows through an auxiliary inductor (Lr) and a capacitor (Cr) for satisfying soft-switching of switches, irrespective of load. So, high conduction losses are induced from resistance of an auxiliary inductor, a capacitor, a printed circuit board (PCB), and switches. To overcome this problem, a soft-switching bidirectional dc-dc converter using a lossless active snubber is discussed in the next section

Soft Switching Bidirectional Dc-Dc Converter with an active snubber

To overcome this problem due to high conduction loss in the conventional soft switching bidirectional converter, a soft-switching bidirectional dc-dc converter using an active snubber circuit is used. Compared with the conventional soft switching bidirectional dc-dc converter, the total amount of the current flowing through the auxiliary circuit is considerably reduced. The converter with an active snubber in two different types are shown in Fig.5 and Fig.6.

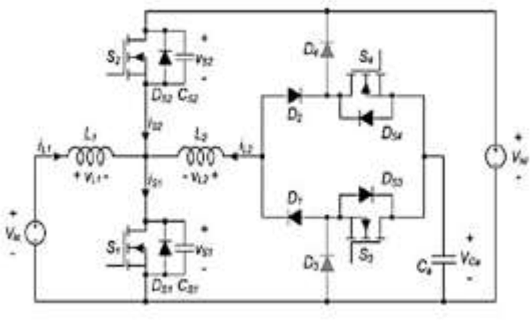

Fig.7. Soft switching bidirectional dc-dc converter using lossless active snubber circuit (1)

The circuit diagram of the bidirectional converter using an active snubber circuit is shown in in Fig.5 [1] and Fig.6 [2].The switch S1 acts as a boost switch in boost operation and a synchronous switch in buck operation. The switch S2 acts as a synchronous switch in boost operation and as a buck switch in buck operation. The lossless active snubber, which consists of an auxiliary inductor L2, an additional capacitor Ca, blocking diodes D1 and D2, and auxiliary switches S3 and S4,is added into the conventional bidirectional dc-dc converter. In order to minimize the conduction loss in the active snubber and provide soft-switching operation of the main switches S1 and S2, the lossless active snubber operates during short time intervals. The diodes Ds1,Ds2, Ds3, and Ds4 are the intrinsic body diodes of S1,S2,S3, and S4 . The diodes D3 and D4 are clamping diodes to clamp the voltages across the auxiliary switches and the blocking diodes in the snubber circuit. The capacitors Cs1 and Cs2 represent the parasitic output capacitances of S1 and S2. Assuming that the capacitance of Ca is large enough, Ca can be considered as a voltage source during a switching period.

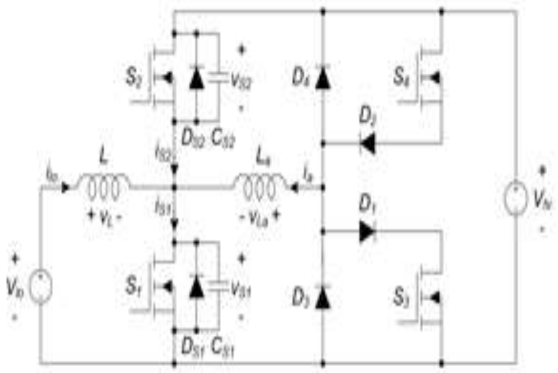

Fig.8. Soft switching bidirectional dc-dc converter using lossless active snubber circuit (2)

In Soft switching bidirectional dc-dc converter using lossless active snubber circuit (1), the total amount of current flowing through the auxiliary inductor is decreased significantly as shown in Fig7.

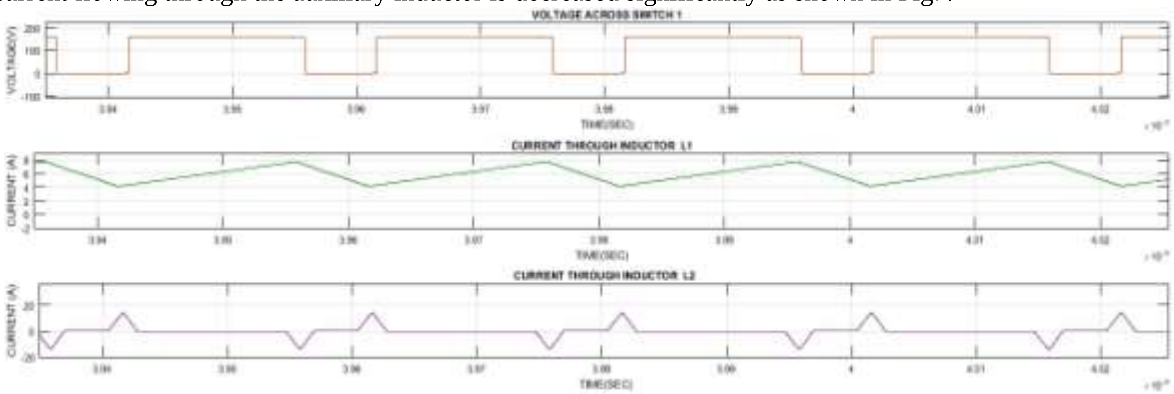

Fig.9. Variation of inductor current IL1 and IL2

It is clear that the total amount of the current flowing through the auxiliary inductor decreased considerably, compared with the conventional soft switching bidirectional dc-dc converter as shown in Fig. 1. So, the total efficiency is improved due to the reduced conduction loss on the auxiliary circuit.

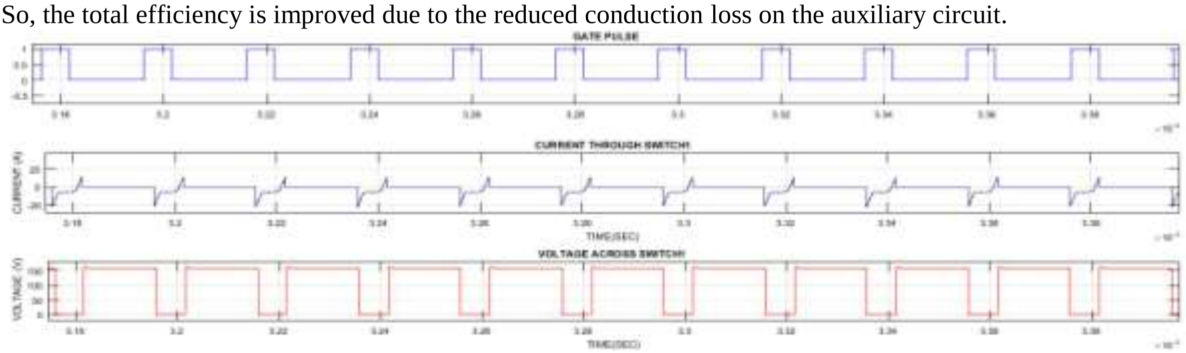

Fig.10. Vgs1, Is1 and Vs1

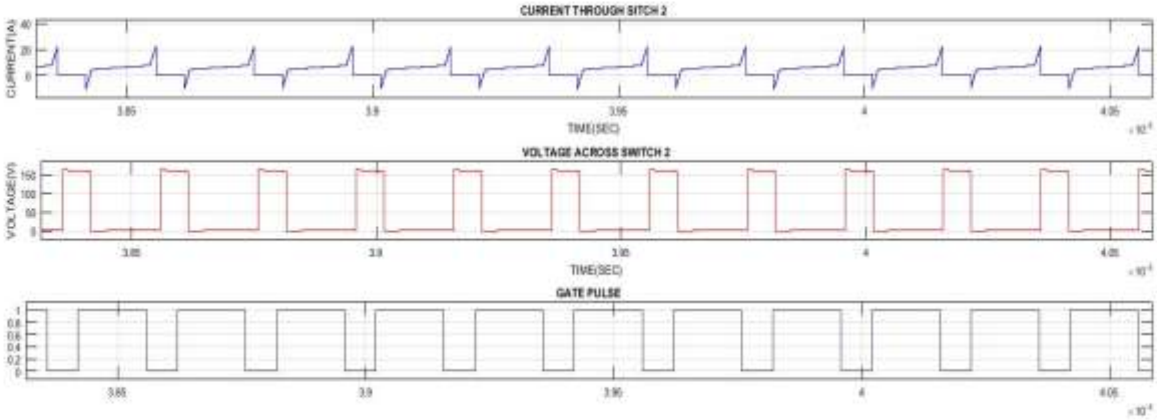

Fig.11. Is2, Vs2 and Vgs2

Soft switching of switches and diodes are shown in Fig.8,9,10 and 11.Zero Voltage Switching (ZVS) waveforms of the main switches S1 and S2 is shown in Fig.8. and 9. Zero Current Switching (ZCS) waveforms of switches 3 and 4 is shown in Fig.9. and 10

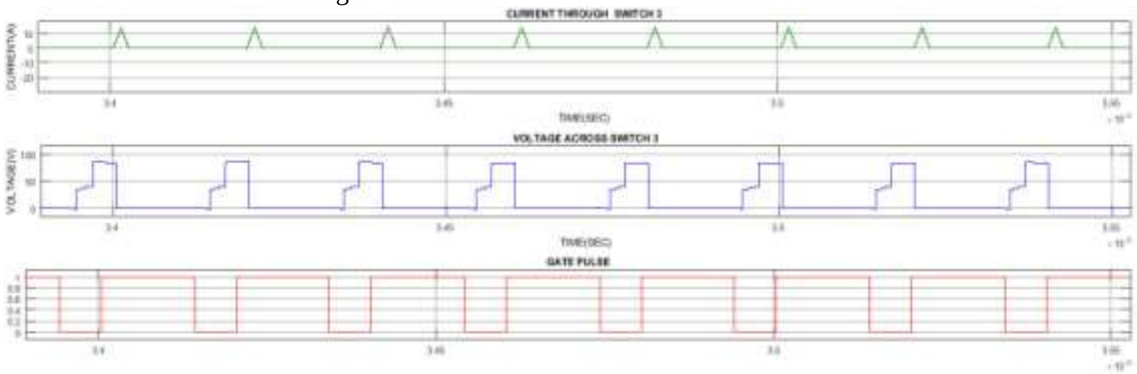

Fig.12. Is3, Vs3 and Vgs3

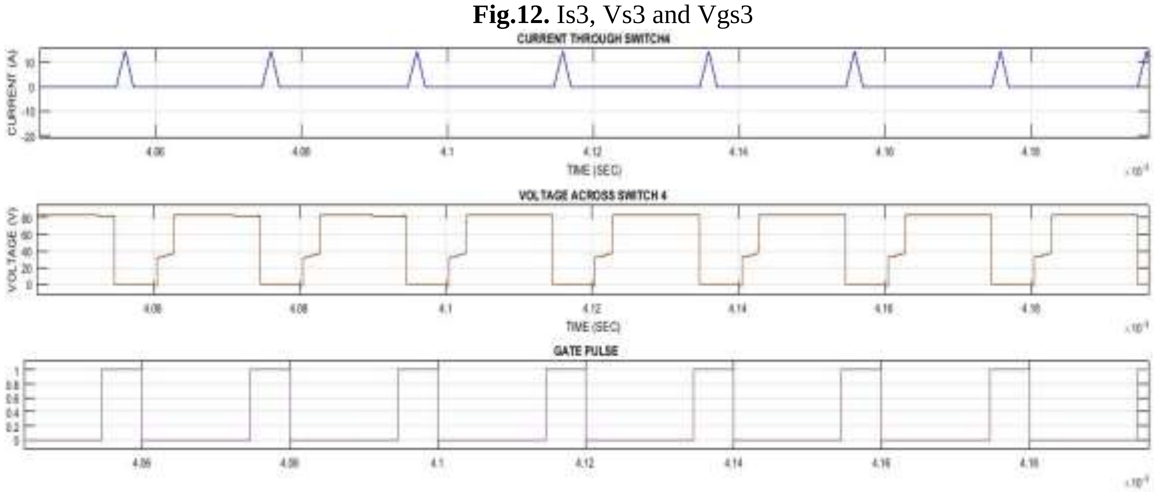

Fig.13. Is4, Vs4 and Vgs4

III. Conclusion

Different soft-switching bidirectional dc-dc converter topologies are introduced in this paper. By using soft switching technique, the switching losses are completely eliminated. To overcome the problems due to conduction loss, an active snubber is inserted in the soft switching bidirectional dc-dc converter. The conduction losses are considerably reduced by the active snubber circuit. In addition, by utilizing the Active snubber circuit, there is no reverse-recovery problem of the intrinsic body diodes of the switches so the overall efficiency of the converter is increased.

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