Soft Switching of Two Quadrant Forward Boost and Reverse Buck DC-DC Converters

Sarath Chandran P C[1]
[1]M.Tech Student
[1]Department of Electronics & Electrical Engineering
[1]Reva Institute of Technology, Bangalore, Karnataka, India

Abstract— This paper explores the Soft switching of two quadrant forward boost and reverse buck dc dc converters. The advantages of this topology is that all active devices operate with soft switching and switching noise is completely suppressed. This is based on the principle of auxiliary resonant commuted pole. Here complete soft switching is achieved in whole operating region. In addition to that active switch loss is reduced and voltage spikes is also suppressed in this topology. The operating principles are explained and the circuits are simulated in MATLAB/SIMULINK.

Key words: Active Snubber, Voltage Spikes, Auxiliary Resonant Commuted Pole

I. INTRODUCTION

As we know Soft switching which forces either the voltage or current to be zero during transition. There are two types of soft switching a) Zero voltage switching b) Zero current switching. There are many ZVS and ZCS techniques employed. One of the soft switching technique which are used in dc-dc converters are called as active snubbers. Active snubbers uses zero voltage transition as well as Zero current transition which are obtained during the main semiconductor turn on process, turn off process and the losses are reduced. This methodology was recently proposed, which was very effective and this could give 99% efficiency.

Even though active snubbers perform well employing the dc dc converters, which have good efficiency and power density. But they lack to suit for the practical applications and additional components need to be coupled with active snubber to get Zero voltage transition and Zero current transition. This costs more because of this designers are avoiding the use of active snubbers in spite of their good switching performance. Fig 2 shows the block diagram of the forward boost and reverse buck dc-dc converter

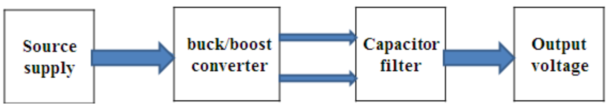


Fig. 1: Block Diagram of The Forward Boost and Reverse Buck Dc-Dc Converter

In order to overcome the disadvantage of active snubber which were employed on dc dc converters. The buck boost topology which had simple topology was introduced based on the auxiliary resonant commuted pole, for soft switching in converters. Here the stress on the main power devices was not increased in order to achieve the soft switching and this feature was not present in the previous topologies. In addition to that soft switching in the whole operating region was achieved irrespective of the load

The above mentioned topology has got many advantages, but problem with voltage spikes which arises across the auxiliary bidirectional switch. . Fig 2 shows the block diagram of segregated loses.

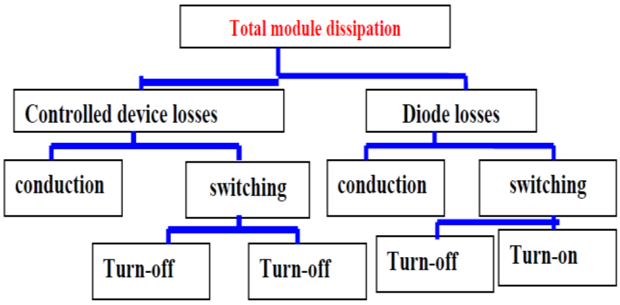


Fig. 2: Segregated Losses

By considering all the disadvantages in the previous topologies, the proposed paper puts forward modified auxiliary circuit which will suppress the voltage spike. By suppressing the voltage spike, the smooth and noiseless waveforms are obtained in the auxiliary circuit.

II. TOPOLOGY DERIVATION

We know the structure of traditional buck boost converter which is shown in the fig 3. it is operating based on the principle of Auxiliary resonant commutated pole

The used snubber is fairly simple yet effective in reducing switching losses and snubber successfully reduces the voltage spike also. the topology operates in two modes forward boost mode(FBM)and reverse buck mode(RBM) and modes can be further subdivided in to eleven time intervals.

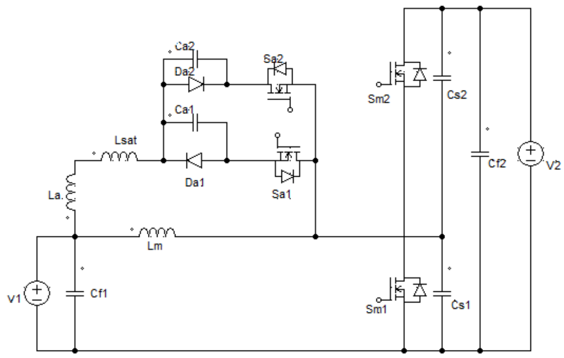


Fig. 4: Forward Boost Reverse Buck Dc-Dc Converter With Simple Snubber

III. OPERATION PRINCIPLE

A. *Forward Boost and the Reverse Buck Operation:*

One switching cycle in forward boost and reverse buck mode may be subdivided into eleven time intervals as shown in Figs. 5 and 6. The auxiliary current pulse is formed during Intervals F1 to F7 and intervals R1 to R7, respectively. These are discussed in detail in Section II-C. Once the auxiliary pulse intervals are over, the operation continues by main circuit intervals shown in Fig. 4 and discussed below.

1) Interval F9 and R9–$t_6 < t < t_7$–Storing Energy in the Main Inductor L_m [see Fig. 7(a)]:

This interval is a standard interval present in conventional hard switched converters. The main current flows from the energy source through the main inductor L_m and the main switch. The main energy portion is stored in L_m during this interval. Duration of this interval defines the difference between the output and input voltage. The duration is often controlled by the voltage controller and the interval ends by turning OFF the main switch.

2) Interval F10 and R10–$t_7 < t < t_8$–ZVS Turn-Off of the Main Switch [see Fig. 7(b)]:

When the main switch turns OFF, the current I_{Lm} commutates almost instantly to the capacitors C_{s1} and C_{s2} . These capacitors serve as turn-off snubber slowing down the voltage change across the main switches, effectively resulting in ZVS turn-off. The snubber capacitors are charged, respectively, discharged by the main current. The interval ends when the charge/discharge cycle is completed. In that moment ,the main diode turns ON and the next interval begins. The auxiliary switch is turned OFF during Interval F9/R9. The turn-off is with ZCS and the voltage difference across the auxiliary switch is equal to zero during the whole Interval F9/R9. Therefore, the parasitic output capacitance of the auxiliary switch only starts charging when the main switch turns OFF at the beginning of Interval F10/R10. The charging of this capacitance also discharges the auxiliary snubber capacitor. The discharge ends when the voltage of the output capacitance of the auxiliary switch is fully charged. The final voltage of the auxiliary snubber capacitor depends primarily on the ratio between its capacitance and the output capacitance of the auxiliary switch as well as on the difference between the input and output voltages. This final voltage is often clamped to zero by the auxiliary diode.

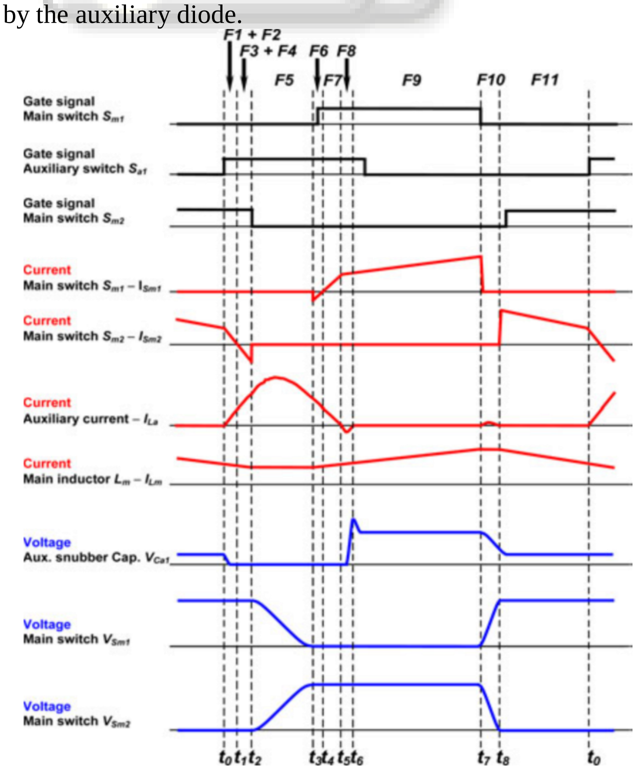


Fig. 5: Basic Wave Forms in the Forward Boost Operation

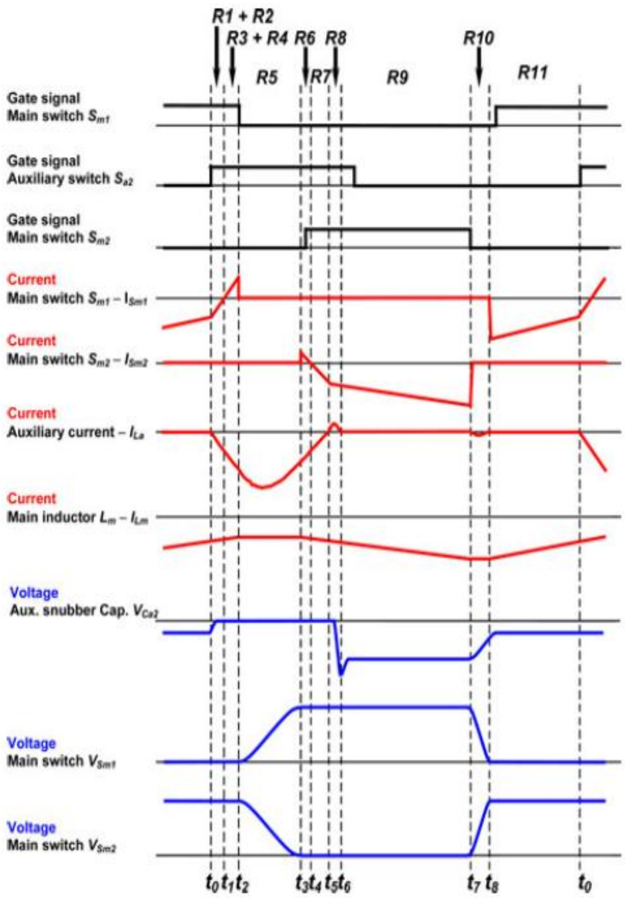


Fig. 6: Basic Wave Forms In The Reverse Buck Operation

3) Interval F11 and R11–$t_8 < t < t_0$–Transferring Energy to the Load Side [see Fig. 7(c)]:

Interval F11/R11 is another of the standard hard switched operating modes. It begins by the main current commutating from the snubber capacitors to the main diode. After a short while ,making sure that the main switch is completely OFF and the whole main current has commutated to the main diode, the switch in parallel to the main diode may be turned ON to enable synchronous rectification (SR). This action “removes” the current from the body diode into the MOSFET channel which reduces the conduction losses as well as reverse recovery of the main diode when it switches OFF in Interval F3/R3. During this interval a part of the energy stored in the main inductor L_m is transferred to the output. The interval ends by turning ON the auxiliary switch and the switching cycle continues by the first auxiliary pulse interval F1/R1

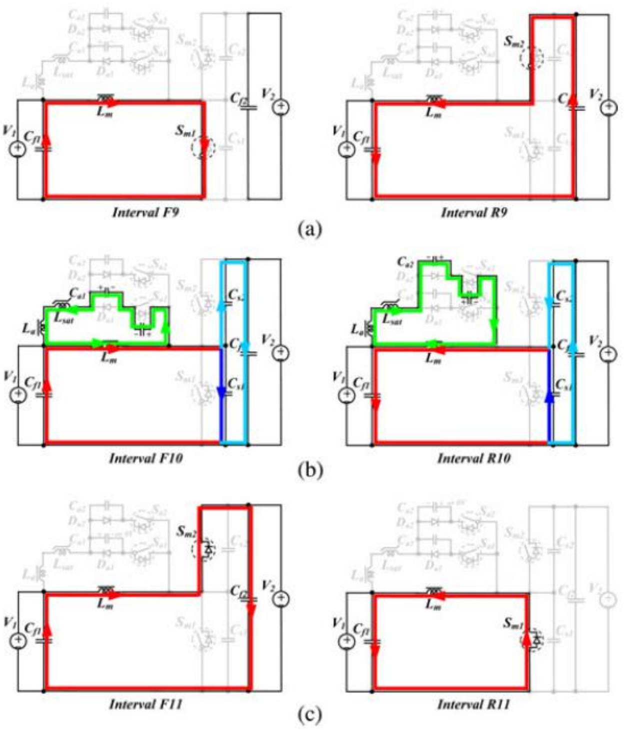


Fig. 7: Main Circuit Intervals In Boost And Buck Operation

B. Boost and Buck Auxiliary Current Pulses:

1) Intervals F1, R1–Damped Discharge of the Auxiliary Snubber Capacitor [see Fig. 8(a)]:

The starting point of this interval is the turn-on of the auxiliary switch. Initially the auxiliary snubber capacitor may be charged to a certain voltage level depending on the operating point. If the capacitor is fully discharged during intervals F10/R10 then this interval is skipped. Otherwise, the capacitor is discharged in a resonant fashion and the auxiliary current commutates to the auxiliary diode. The rate of discharge is defined by the sumof the auxiliary inductance L_a and saturable inductance L_{sat} in its unsaturated state. The value of the snubber capacitor is in the order of a few *nF* and, therefore, the discharge is fast in spite of the large inductance (L_{sat} prior to saturation). At the beginning of this interval, the current through the auxiliary circuit is zero and, therefore, the auxiliary switch turns ON with ZCS. As discussed previously, the auxiliary diode turns ON essentially with ZVS in all operating points due to the presence of the auxiliary snubber capacitor. The next interval begins when the auxiliary diode turns ON.

2) Interval F2, R2–Main Current Commutation to AuxiliaryCircuit [see Fig. 8(b)]:

The interval begins when the auxiliary capacitor is fully discharged and the auxiliary current starts flowing through the auxiliary diode. The main current I_{Lm} commutates from the main switch to the auxiliary circuit. The saturable inductor L_{sat} saturates a short while after the beginning of the interval. The rate of the current rise during this interval is limited by the auxiliary inductor L_a together with the residual inductance of the saturable inductor. This rate is defined by (1) in case of F2 and by (2) in case of R2

$$di_{a1}/dt = (V_2 - V_1)/L_{a\_o} \qquad (1)$$

$$di_{a2}/dt = V_1/L_{a\_i} \qquad (2)$$

where L_{a_o} is the total auxiliary inductance present in the auxiliary path between the input capacitor C_{f1} and output capacitor C_{f2}, and L_{a_i} is the auxiliary inductance including connections to the input filter capacitor C_{f1}. The two values may slightly differ depending on the converter structural layout. The auxiliary current continues to rise until the moment it reaches the value of the main inductor current. In the same time, the current in the main switch reaches zero and the operation continues by the next time interval.

3) Interval F3, R3–Reverse Recovery of the Main Diode [see Fig. 8(c)]:

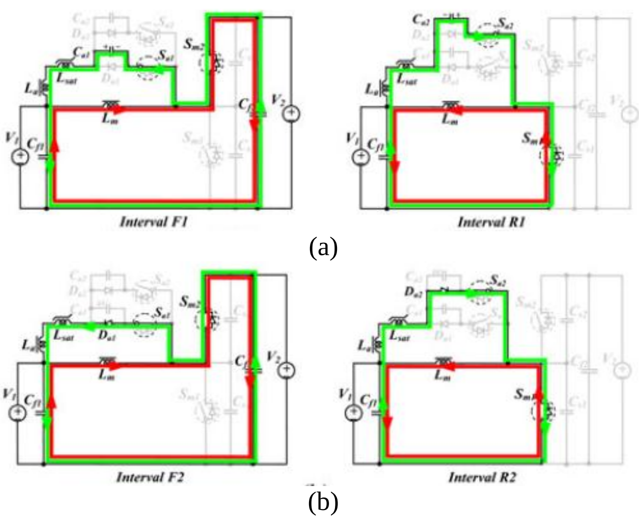
At the beginning of this interval, the main current has commutated fully to the auxiliary circuit and, therefore, the main diode must go through its reverse recovery. The recovery proceeds with the same *di/dt* as present in the previous interval. Selection of the auxiliary inductance L_a provides a degree of control over the *di/dt* and hence over the reverse recovery. If SR is used and ERC is not required for complete soft switching, the SR switch should be turned OFF at the zero current crossing to minimise the recovery. Once the recovery is over, the operation continues by Interval F5, R5. If ERC is required, the SR switch remains ON beyond the zero current crossing and the circuit operation continues by the following time interval.

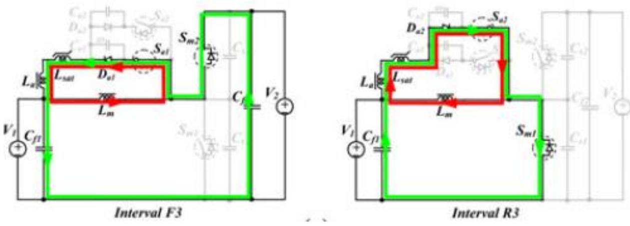
4) Interval F4, R4–Building Up Current for the Complete ZVS Turn-Off of the Main Switch [see Fig. 8(d)]:

This interval is used if the complete soft switching cannot be attained due to low load or small ratio between the input and output voltage. The auxiliary current continues rising with *di/dt* defined by (1), respectively, (2). SR is turned OFF when the auxiliary current reaches the value required for complete soft switching and the next interval begins.

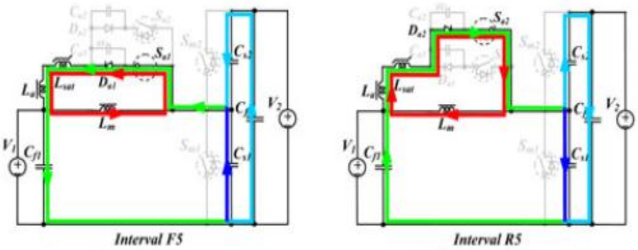
5) Interval F5, R5–Resonant Main Voltage Commutation [see Fig. 8(e)]:

At the beginning of this interval, the auxiliary current commutates to the snubber capacitors C_{s1} and C_{s2} . These can now be fully charged, respectively, discharged since the current has a required or higher than required value. The minimum auxiliary current required for complete resonant voltage transition and hence complete ZVS of main switches can be calculated by (3) for the boost pulse and by (4) for the buck auxiliary pulse





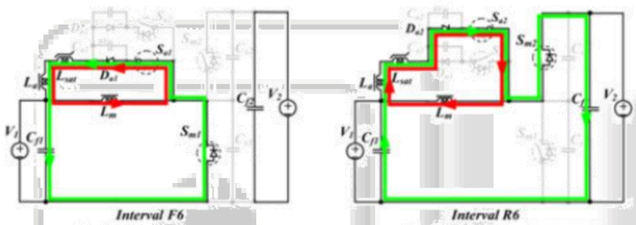
(C)



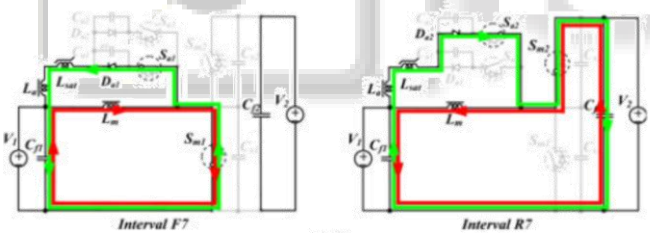
(d)

$$I_{La\_\min} = V_2 \cdot \sqrt{\frac{C_{s1}+C_{s2}}{L_{a\_o}} \cdot \left(2\frac{V_1}{V_2} - 1\right)} \qquad (3)$$

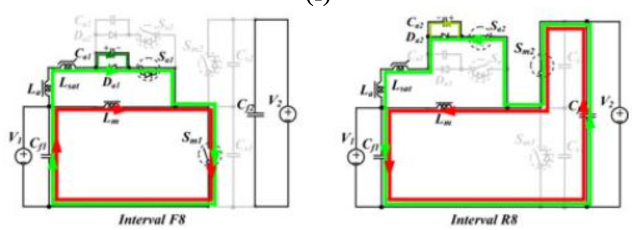
$$I_{La\_\min} = V_2 \cdot \sqrt{\frac{C_{s1}+C_{s2}}{L_{a\_o}} \cdot \left(1 - 2\frac{V_1}{V_2}\right)}. \qquad (4)$$



(E)



(f)



(g)

Fig. 8:Operating Modes Involved In Forming Of Auxiliary Current Pulse

These equations apply for the output to input voltage ratio less than two in case of the boost and more than two in case of the buck pulse. In case of other voltage ratios, complete soft switching is possible even at zero current. The charge and discharge processes can both be described by the following differential equations: .

$$di_{aCs1}/dt = \left(V_1 - 1/C_{s1}\int i_{aCs1}\cdot dt\right)\Big/L_{a\_i} \qquad (5)$$

$$di_{aCs2}/dt = \left(V_2 - V_1 - 1/C_{s2}\int i_{aCs2}\cdot dt\right)\Big/L_{a\_o} \qquad (6)$$

$$V_2 = 1/C_{s1}\int i_{aCs1}dt + 1\Big/C_{s2}\int i_{aCs2}dt. \qquad (7)$$

The only difference between the two auxiliary pulses is in the initial conditions. The interval ends when the resonant transition is finished. In that instant, the auxiliary current commutates into the antiparallel diode of the main switch and the next interval begins.

6) Interval F6, R6,–ZVS Turn-On of the Main Switch [see Fig. 8(f)]:

The current flow through the antiparallel diode of the main switch clamps the voltage across the switch to a near zero value, enabling ZVS turn-on. The main switch can be turned ON with ZVS during the whole duration of this interval. The auxiliary current is reduced with *di/dt* calculated by (2) in case of the boost pulse, respectively, (1) in case of the buck pulse. The current reduction in the auxiliary circuit results in a current reduction in the antiparallel diode as well. When the current in the diode reaches zero, it commutates into the main switch and this time interval ends.

7) Interval F7, R7–Main Current Commutation From the /Auxiliary Circuit to the Main Switch [see Fig. 8(g)]:

During this interval, the main current slowly commutates from the auxiliary to the main switch. The commutation rate is identical to the previous interval. When the auxiliary current reaches zero and main switch carries the whole main current, the operation continues by reverse recovery of the auxiliary diode.

8) Interval F8, R8–Reverse Recovery of an Auxiliary Diode [see Fig. 8(h)]:

The reverse recovery of an auxiliary diode is softened by the saturable inductance L_{sat} in its unsaturated state. When the recovery current stops, the rate of voltage rise across the diode is reduced by the auxiliary snubber capacitor and the overvoltage across the auxiliary diode is controlled. Depending on the circuit design, there may be a small overshoot due to the resonant character of the charge control circuit comprising of L_a, L_{sat} and the lack of clamping. The auxiliary switch may be turned OFF at any moment after the end of this interval and before turning OFF the main switch .

In the case of a hybrid mode, the overlap of the two auxiliary switches should be avoided in order to prevent undesired circuit response. The turn-off is in all conditions under ZCS due to zero current flowing through the auxiliary switch when the turnoff command is given. In the same time, the auxiliary snubber capacitor provides ZVS conditions and therefore the turn-off is under ZCS combined with ZVS.

IV. Simulation Results

As we have understood the circuit operation in the section III, now it is necessary to simulate the circuits in MATLAB/SIMULINK. The parameters for the simulation is shown in the below table. Both the circuit topologies have been simulated which are shown in the Fig 9 and Fig 10.The results of the both topologies are shown in the Fig 11 and Fig 12. Both the voltage waveforms of boost and buck boost converter

Nominal input voltage V_{IN}	200 V
Nominal output voltage V_{2N}	400 V
Maximum input current I_{1M}	70 A
Nominal output power P_{2N}	14 kW
Operating frequency f_s	62.5 kHz

Main inductor L_m	50 µH
Aux. inductor L_a	1.2 µH
Sat. inductor L_{sat}	4 x W914 [18]
Decoupling inductors L_{d1}, L_{d2}	320 nH
Snubber capacitors C_{s1_1}, C_{s1_2}, C_{s2_1}, C_{s2_2}	2 x 3.6 nF
Aux. snubber capacitors C_{a1}, C_{a2}	0.9 nF
Main switch S_{m1}, S_{m2}	2 x STY112N65M5 [19]
Parallel diodes D_p	DSEE29-12CC [20]
Aux. switch S_{a1}, S_{a2}	IRG4PSC71UD [21]
Aux. diodes D_{a1}, D_{a2}	DSEE29-12CC [20]
DSP controller	TMS320F28335 [22]

Table 1: Parameters for Simulation

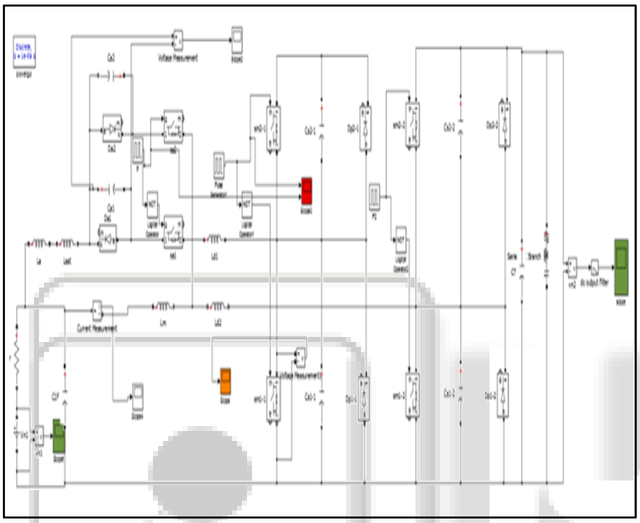


Fig. 9: Simulation of Forwad Boost Mode

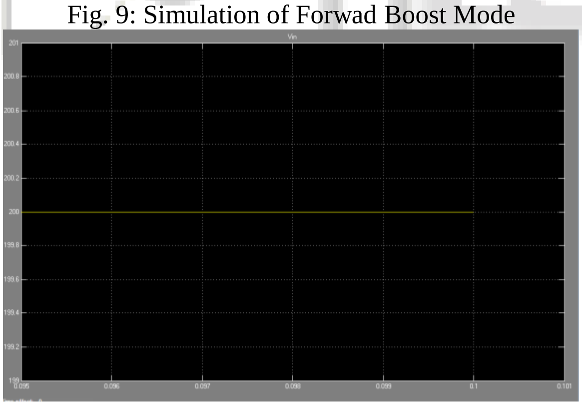


Fig. 10: Input Voltage In Boost Mode

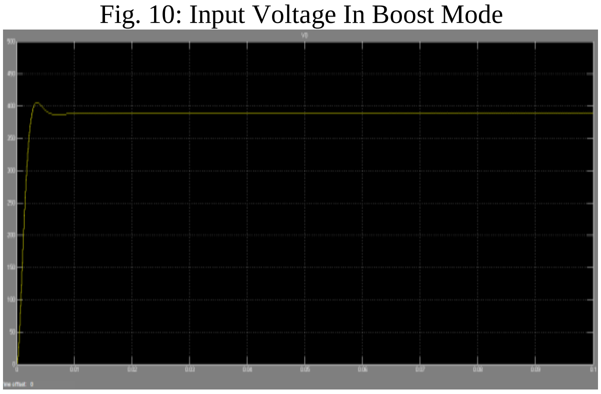


Fig. 11: Output Voltage In Boost Mode

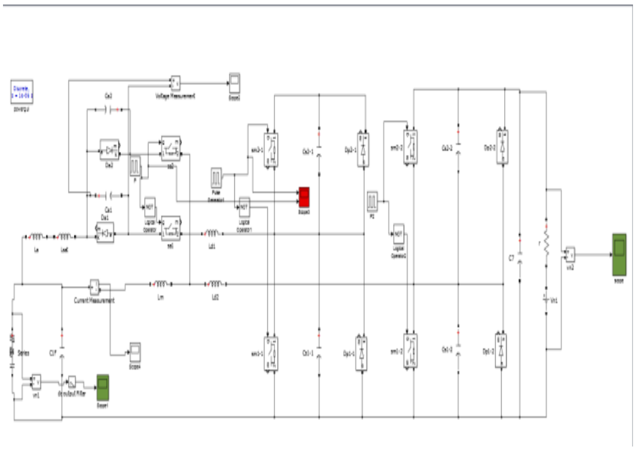


Fig. 10: Simulation of Circuit Mentioned In Fig 2.2

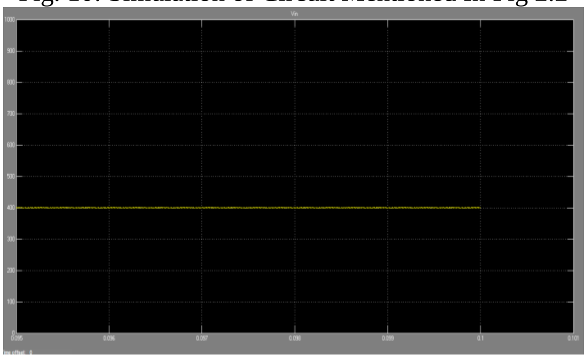


Fig. 12: Input Voltage In Buck Mode

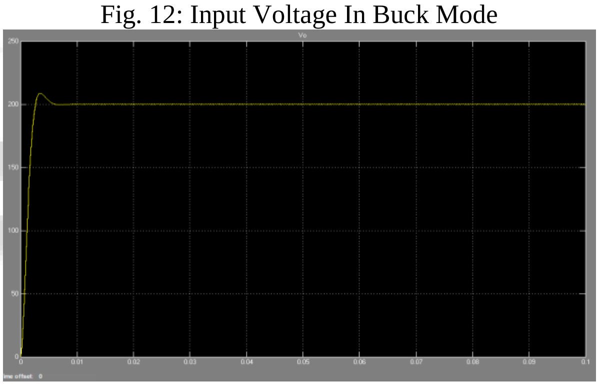


Fig. 13: Output Voltage In Buck Mode

V. CONCLUSION

This paper presents a novel Soft Switching of two quadrant Forward boost and Reverse buck dc-dc Converters. it is based on the principle of auxiliary resonant commutated pole. the proposed circuit has fuly achieved soft switching, low stress ,noiseless waveforms for all components. the efficiency will be maximum .the prototype specification target application in drive trains of electric, hybrid, and fuel cell vehicles.

The main motivation is the proposed topology was also to keep it as simple as possible. operation principle is explained in detail and circuits have been simulated in Matlab/Simulink, thus results are verified.

REFERENCES

[1] H. Bodur and A. F. Bakan, "A new ZVT-PWM DC-DC converter," IEEE Trans. Power Electron., vol. 17, no. 1, pp. 40–47, Jan. 2002.

[2] H. Bodur and A. F. Bakan, "A new ZVT-ZCT-PWM DC-DC converter," IEEE Trans. Power Electron., vol. 19, no. 3, pp. 676–684, May 2004.

[3] M. Pavlovsky, Y. Tsuruta, and A. Kawamura, "Bi-directional buck/boost dc-dc converter with ultra high efficiency based on improved SAZZ topology," in Proc. Energy Convers. Cong. Exposition, ECCE 2009, pp. 1783-1790.
[4] S. Chattopadhyay, S. Baratam, and H. Agrawal, "A new family of active clamp PWM dc-dc converters with ZVS for main switch and ZCS for auxiliary switch," in Proc. Applied Power Electron. Conf. Exposition, APEC 2011, pp. 851–858.
[5] A. Elasser and D. A. Torrey, "Soft switching active snubbers for DC/DC converters," IEEE Trans. Power Electron., vol. 11, no. 5, pp. 710–722, Sep. 1996.
[6] I. Aksoy, H. Bodur, and A. F. Bakan, "A New ZVT-ZCT-PWM DC–DC Converter," IEEE Trans. Power Electron., vol. 25, no. 8, pp. 2093–2105, Aug. 2010.
[7] B. Ivanovic and Z. Stojiljkovic, "A novel active soft switching snubber designed for boost converter," IEEE Trans. Power Electron., vol. 19, no. 3, pp. 658–665, May 2004.
[8] K-J. Lee, B.-G. Park, R-Y. Kim, and D-S. Hyun, "Nonisolated ZVT twoinductor boost converter with a single resonant inductor for high step-up applications," IEEE Trans. Power Electron., vol. 27, no. 4, pp. 1966–1973, Apr. 2012.
[9] T.-F. Wu, Y.-D. Chang, C.-H. Chang, and J.-G. Yang, "Soft-switching boost converter with a flyback snubber for high power applications," IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1108–1119, Mar. 2012.

