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Design of Bidirectional Dc/Dc Converter for Electric vehicle Using Split Battery Charging/Discharging

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Abstract:
In this paper a soft-switching bidirectional converter using a lossless with active driver circuit has been proposed. Proposed converter performs ZVS (Zero Voltage Switching) of the main switches and ZCS (Zero Current Switching from auxiliary switches obtained to maintain stability in converter. In addition, by utilizing the active driver circuit, issues on reverse-recovery problem of the intrinsic body diodes of the switches are reduced. Driver circuit needs to operate in a short duration; the improved conduction loss of the proposed converter is relatively lower than the conventional soft-switching bidirectional converter. Thus, the overall efficiency improvement achieved over a wide range of load. Moreover, by adjusting according to loads, it is possible to achieve optimized overall efficiency throughout the whole loading range. Real time, the DC motor has been speed controlled by the duty cycle of the switches. A integrated controller has been designed and simulated for the control of the both the modes i.e. motoring as well as scope of simulation in MATLAB.

***Keywords**: Converters, battery, DC Motors, ZVS, ZCS, Matlab.*

I.INTRODUCTION

In recent years, alternative energy systems and applications like eco-friendly cars have been focused on due to the exhaustion of fossil fuel and severe environmental pollution. Bidirectional dc-dc converters are one of the most important energy conversion system in the applications such as plug-in hybrid electric vehicle (PHEV), fuel-cell vehicle, renewable energy system, and uninterruptible power supply (UPS). In PHEV system, the bidirectional dc-dc converter acts as an energy transfer system from a low voltage battery to a DC-link that is an input voltage of an inverter for operating a vehicle motor, or from a DC-link to a battery for charging regenerative energy. In the renewable energy systems, including fuel cell systems, photovoltaic systems, and wind power systems, the bidirectional dc-dc converter is essential for electric power conversion between a low voltage battery where dump power is charged and a high voltage source for home appliances. The bidirectional dc-dc converter is divided into an isolated type and a non-isolated type. On the other hand, the non-isolated bidirectional dc-dc converter has high efficiency due to simple structure. Recently, 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. With the purpose of improving the efficiency of the drive train and to minimize the dependency on the petroleum fuels two or more sources of the propulsions (Including ICE) are being employed in the vehicles.This are known as the Hybrid Electric Vehicles (HEVs). The topological overview of the various hybrid drive trains and the comparisons between them has been presented in. The role and

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the requirement of the power electronics and dc-dc converter in the HEV technology was reviewed and explained in. The comparisons between the various non isolated Bidirectional DC -DC converters on the basis of their performance has been done in. Motor selection and the various drive train issues depending up on the traction drive requirements and operational performance has been done in.The power stage design methodology and the ZVRT switching was introduced in [It also the implemented the DCM operation for the power density maximization of the converter. The concepts of the soft switching techniques for the efficiency improvement and the device stress reduction was presented in the. The unified controller for a current mode controlled bidirectional DC-DC converter was presented in.In existing system using soft-switching bidirectional dc/dc converter with a *LC* series resonant circuit. The converter has been obtained by adding *LC* series resonant tank in the conventional bidirectional dc/dc converter. The topology performs soft switching at both buck and boost operations. Through the theoretical boost and buck mode analysis, zero voltage switching problem High.

II. PROPOSED SYSTEM

A soft-switching bidirectional dc-dc converter using a lossless active snubber is proposed in this paper. In the proposed converter, 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. Moreover, there is no reverse recovery problem of the intrinsic body diodes of the switches. To verify the ZVS of the main switches and efficiency improvement of the proposed bidirectional dc-dc converter, theoretical analysis and experimental results from a 200 W prototype are discussed. in Proposed the DC motor has been speed controlled by the duty cycle of the switches. A unified controller has been designed and simulated for the control of the both the modes.

2.1EXISTING SYSTEM BLOCK DIAGRAM:

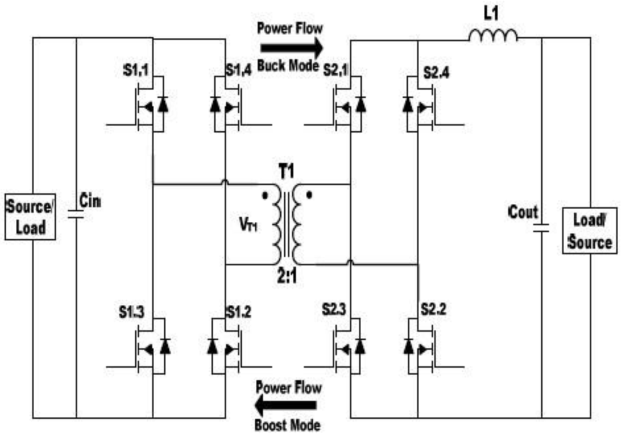

Fig. 1. Existing block diagram

2.2PROPOSED SYSTEM BLOCK DIAGRAM:

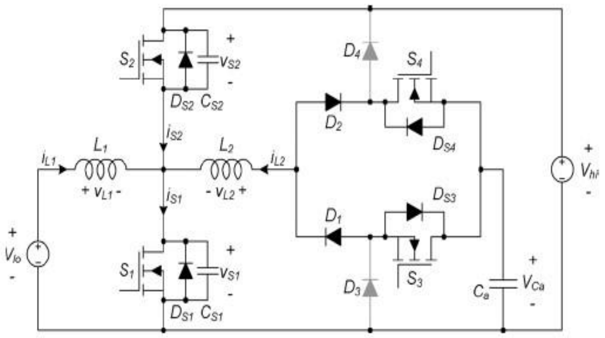

Fig. 2. Proposed block diagram

A boost converter (step-up converter) is a power converterwith an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS)containing at least two semiconductorswitches (a diodeand a transistor) and at least one energystorage element. Filters made of capacitors(sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

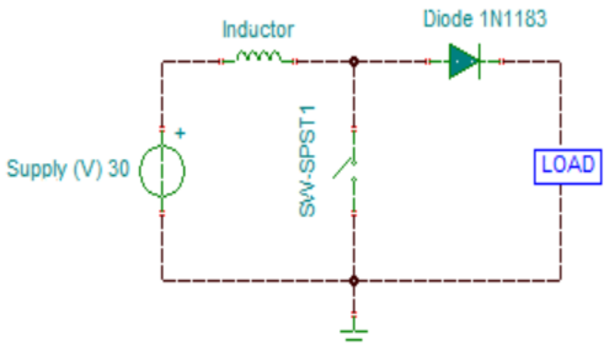

Fig.3. Boost converter circuit diagram

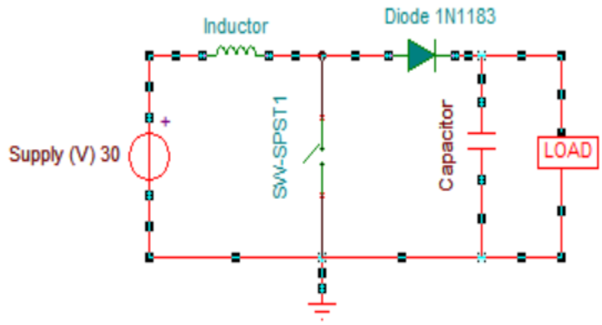

Fig.6. Closedcircuit configurations of a boost converter.

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

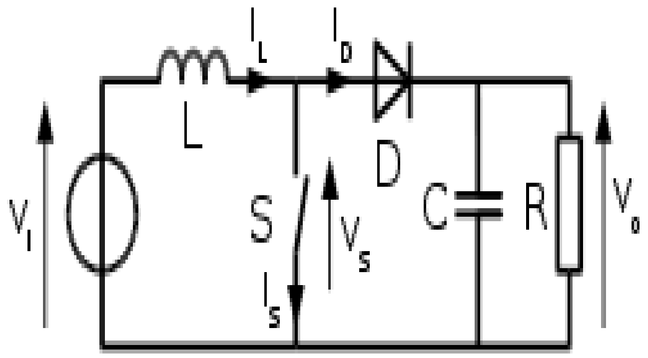

Fig.4: Boost converter schematic diagram

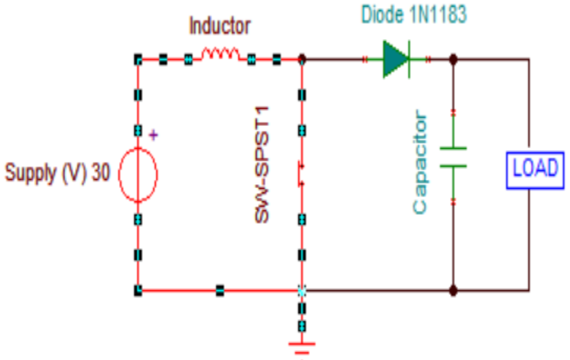

Fig.5. Closedcircuit configurations of a boost converter.

The basic principle of a Boost converter consists of 2 distinct states

- In the On-state, the switch S (see figure 5) is closed, resulting in an increase in the inductor current.
- In the Off-state, the switch is open and the only path offered to inductor current is through the fly back-diodeD, the capacitor C and the load R. This results in transferring the energy accumulated during the On-state into the capacitor.
- The input current is the same as the inductor current as can be seen in figure 6. So it is not discontinuous as in the buck converterand the requirements on the input filter are relaxed compared to a buck converter.

2.3CONTINUOUS MODE

When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. Figure 7 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calcula3ted as follows, in the case of an ideal converter (i.e. using components with an ideal behaviour) operating in steady conditions:

During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \qquad (1)$$

At the end of the On-state, the increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i \qquad (2)$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (S is always on).

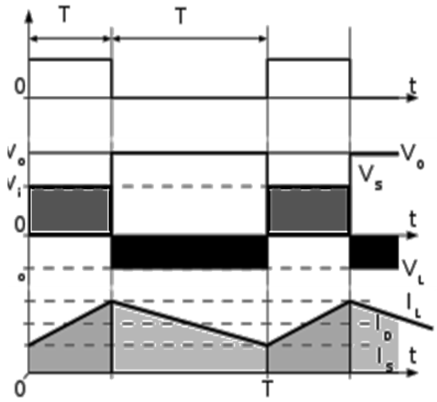

Fig. 7. Waveforms of current and voltage in a boostconverter operating in continuous mode.

During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_o = L\frac{dI_L}{dt} \qquad (3)$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta I_{L_{Off}} = \int_0^{(1-D)T} \frac{(V_i - V_o)\,dt}{L} = \frac{(V_i - V_o)(1-D)T}{L} \qquad (4)$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2}LI_L^2 \qquad (5)$$

So, the inductor current has to be the same at the start and end of the commutation cycle.

This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0 \qquad (6)$$

Substituting $\Delta I_{L_{On}}$an$\Delta I_{L_{Off}}$by their expression's yields:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0 \qquad (7)$$

This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1-D} \qquad (8)$$

Which in turns reveals the duty cycle to be:

$$D = 1 - \frac{V_i}{V_o} \qquad (9)$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

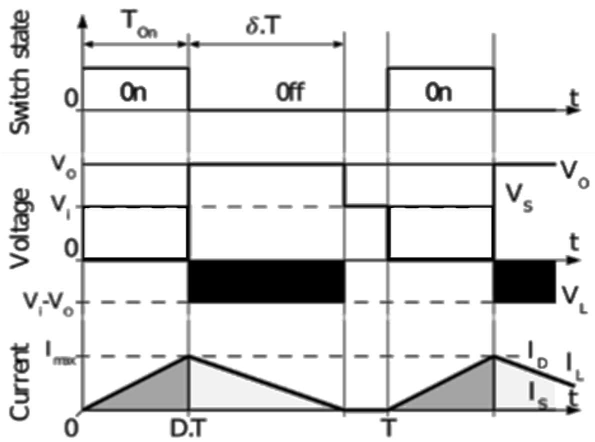

Fig. 8. Waveforms of current and voltage in a boost converter operating in discontinuous mode.

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In some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see waveforms in figure 8). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows: As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{Max}}$(at $t = DT$) is

$$I_{L_{Max}} = \frac{V_i DT}{L} \qquad (10)$$

During the off-period, I_L falls to zero after δT:

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0 \qquad (11)$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i} \qquad (12)$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off state. Therefore, the output current can be written as:

$$I_o = \bar{I}_D = \frac{I_{L_{max}}}{2}\delta \qquad (13)$$

Replacing ILmax and δ by their respective expression's yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)} \qquad (14)$$

Therefore, the output voltage gain can be written as flow:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2 L I_o} \qquad (15)$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current.

2.4BUCK CONVERTER

A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supplythat uses two switches (a transistor and a diode), an inductor and a capacitor. The simplest way to reduce a DC voltage is to use a voltage dividercircuit, but voltage dividers waste energy, since they operate by bleeding off excess power as heat; also, output voltage isn't regulated (varies with input voltage). Buck converters, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating, making them useful for tasks such as converting the 12–24 V typical battery voltage in a laptop down to the few volts needed bythe processor.

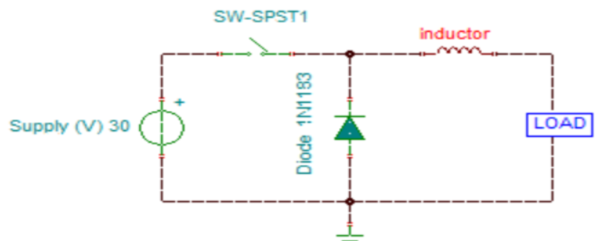

Fig.9. Buck converter circuit diagram.

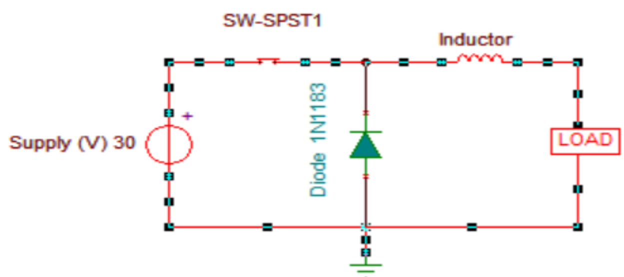

Fig. 10.Closedconfigurations of a buck converter

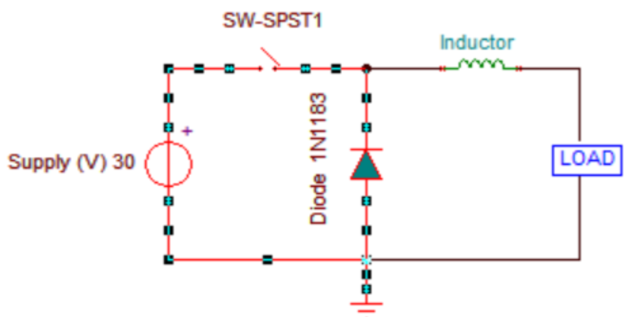

Fig. 11.Open configurations of a buck converter

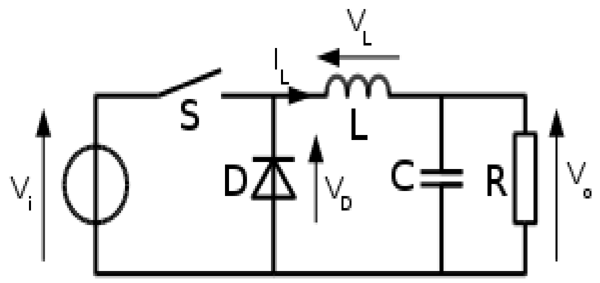

Fig. 12. Buck converter schematic diagram

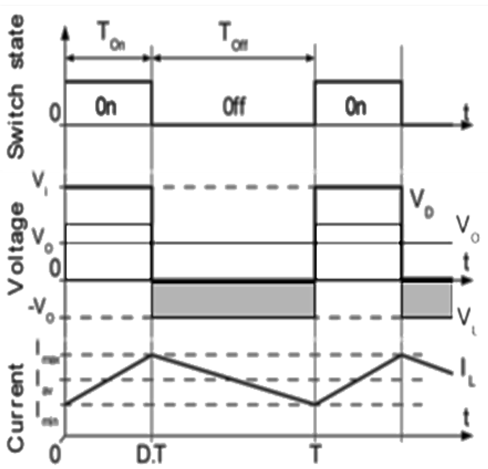

Fig.13. An ideal buck converter operating in continuous mode.

The operation of the buck converter is fairly simple, with an inductorand two switches (usually a transistorand a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

- A buck converter operates in continuous mode if the current through the inductor (I_L) never falls to zero during the commutation cycle. In this mode, the operating principle is described by the chronogram in figure 10.
- When the switch pictured above is closed (On-state, top of figure 9.1), the voltage across the inductor is $V_L = V_i - V_o$. The current through the inductor rises linearly. As the diode is reverse biased by the voltage source V, no current flows through it.
- When the switch is opened (off state, bottom of figure 9.2), the diode is forward biased. The voltage across the inductor is $V_L = -V_o$ (neglecting diode drop). Current I_L decreases.

The energy stored in inductor L is

$$E = \frac{1}{2} L \times I_L^2 \quad (16)$$

Therefore, it can be seen that the energy stored in L increases during On-time (as I_L increases) and then decreases during the Off-state. L is used to transfer energy from the input to the output of the converter.

The rate of change of I_L can be calculated from:

$$V_L = L\frac{dI_L}{dt} \quad (17)$$

With V_L equal to $V_i - V_o$ during the On-state and to $-V_o$ during the Off-state. Therefore, the increase in current during the On-state is given by:

$$\Delta I_{L_{on}} = \int_0^{t_{on}} \frac{V_L}{L}\, dt = \frac{(V_i - V_o)}{L} t_{on} \quad (18)$$

Identically, the decrease in current during the Off state is given by:

$$\Delta I_{L_{off}} = \int_0^{t_{off}} \frac{V_L}{L}\, dt = -\frac{V_o}{L} t_{off} \quad (19)$$

If we assume that the converter operates in steady state, the energy stored in each component at the end of a commutation cycle T is equal to that at the beginning of the cycle. That means that the current I_L is the same at t=0 and at t=T (see figure 4). Therefore, so we can write from the above equations:

$$\frac{(V_i - V_o)}{L} t_{on} - \frac{V_o}{L} t_{off} = 0 \quad (20)$$

It is worth noting that the above integrations can be done graphically: In figure 4, $\Delta I_{L_{on}}$ is proportional to the area of the yellow surface, and $\Delta I_{L_{off}}$ to the area of the orange surface, as these surfaces are defined by the inductor voltage (red) curve. As these surfaces are simple rectangles, their areas can be found easily: $(V_i - V_o) t_{on}$ for the yellow rectangle and $-V_o t_{off}$ for the orange one. For steady state operation, these areas must be equal.

$$t_{on} = DT \text{ and } t_{off} = (1-D)T \quad (21)$$

D is a scalar called the *duty cycle* with a value between 0 and 1. These yields:

$$(V_i - V_o)DT - V_o(1-D)T = 0$$
$$\Rightarrow V_o - DV_i = 0$$
$$\Rightarrow D = \frac{V_o}{V_i} \quad (22)$$

From this equation, the output voltage of the converter varies linearly with the duty cycle for a given input voltage. As the duty cycle D is equal to the ratio between t_{On} and the period T, it cannot be more than 1. Therefore, $V_o \le V_i$. Therefore, this converter is referred to as step-down converter. So, for example, stepping 12 V down to 3 V (output voltage equal to a fourth of the input voltage) would require a duty cycle of 25%, in our theoretically ideal circuit.

2.5 DISCONTINUOUS MODE

In some cases, the amount of energy required by the load is small enough to be transferred in a time lower than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see figure 5). This has, however, some effect on the previous equations.

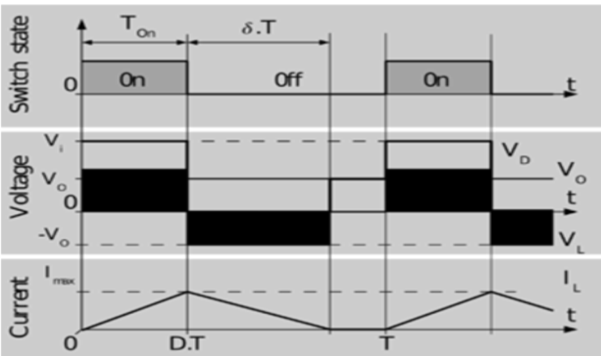

Fig. 14. An ideal buck converter operating in discontinuous mode.

We still consider that the converter operates in steady state. Therefore, the energy in the inductor is the same at the beginning and at the end of the cycle (in the case of discontinuous mode, it is zero). This means that the average value of the inductor voltage (V_L) is zero; i.e., that the area of the yellow and orange rectangles in figure 5 are the same.

These yields:

$$(V_i - V_o)DT - V_o\delta T = 0 \quad (23)$$

So the value of δ is:

$$\delta = \frac{V_i - V_o}{V_o}D \quad (24)$$

The output current delivered to the load (I_o) is constant, as we consider that the output capacitor is large enough to maintain a constant voltage across its terminals during a commutation cycle. This implies that the current flowing through the capacitor has a zero-average value. Therefore, we have:

$$\bar{I}_L = I_o \quad (25)$$

Where $\bar{I}_L$ is the average value of the inductor current. As can be seen in figure 5, the inductor current waveform has a triangular shape. Therefore, the average value of I_L can be sorted out geometrically as follow:

$$\bar{I}_L = \left(\frac{1}{2}I_{L_{max}}DT + \frac{1}{2}I_{L_{max}}\delta T\right)\frac{1}{T}$$
$$= \frac{I_{L_{max}}(D+\delta)}{2}$$
$$= I_o \quad (26)$$

The inductor current is zero at the beginning and rises during t_{on} up to I_{Lmax}. That means that I_{Lmax} is equal to:

$$I_{L_{Max}} = \frac{V_i - V_o}{L}DT \quad (27)$$

Substituting the value of I_{Lmax} in the previous equation leads to:

$$I_o = \frac{(V_i - V_o)DT(D+\delta)}{2L} \quad (28)$$

And substituting δ by the expression given above yields:

$$I_o = \frac{(V_i - V_o)DT\left(D + \frac{V_i - V_o}{V_o}D\right)}{2L} \quad (29)$$

This latter expression can be written as:

$$V_o = V_i \frac{1}{\frac{2LI_o}{D^2 V_i T} + 1} \qquad (30)$$

It can be seen that the output voltage of a buck converter operating in discontinuous mode is much more complicated than its counterpart of the continuous mode. Furthermore, the output voltage is now a function not only of the input voltage (V_i) and the duty cycle D, but also of the inductor value (L), the commutation period (T) and the output current (I_o).

III. EXPERIMENTAL VALIDATION

MATLAB has several auxiliary Toolboxes distributed by Math works, Inc., which are useful in constructing models and simulating dynamical systems. These include the System Identification Toolbox, the Optimization Toolbox, and the Control System Toolbox. These toolboxes are collections of m-files that have been developed for specialized applications. There is also a specialized application, Simulink, which is useful in modular construction and real time simulation of dynamical systems.

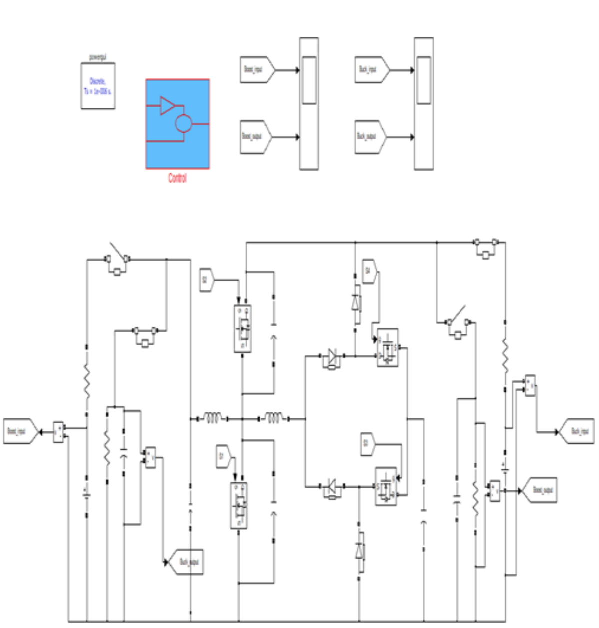

Fig. 15. Modelling of Proposed System

IV. SIMULATION RESULT

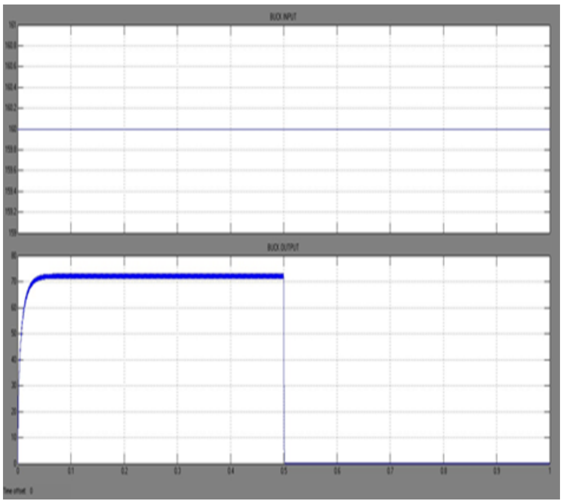

Fig. 16. Buck Input and Output

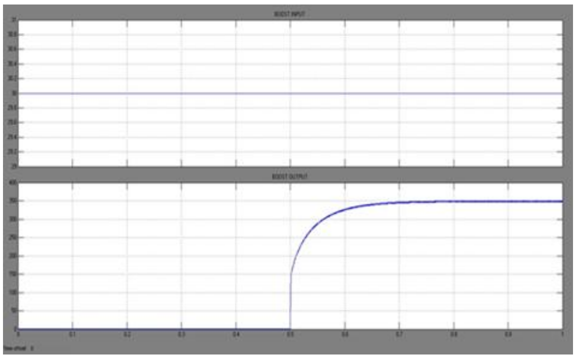

Fig. 17. Boost Input and Output

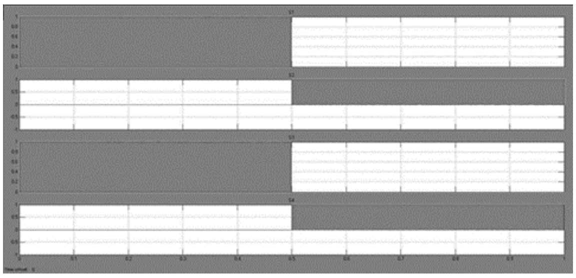

Fig. 18. Switching Pulses

From the above, MatLab Simulink output waveforms we can see that, for buck operation the given input voltage 160 volt reduces by buck operation and reduces the output voltage to 70 volt and for boost operation the given input voltage 30 volt increases by boost operation and reduces the output voltage to 350 volt.

V. CONCLUSION

In this paper, a soft-switching bidirectional dc-dc converter using a lossless active snubber has been proposed. In the proposed converter, ZVS of the main switches and ZCS of the auxiliary switches are always achieved. In addition, by utilizing the active snubber, there is no reverse-recovery problem of the intrinsic body diodes of the switches. Since the active snubber operates in a short time, the increased conduction loss of the proposed converter is relatively lower than the soft-switching bidirectional converter. Thus, the overall efficiency improvement is achieved over a wide range of load. Moreover, by adjusting according to loads, it is possible to achieve optimized overall efficiency throughout the whole loading range.

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