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Analysis of Bi-directional DC-DC Buck-Boost Quadratic Converter for Energy Storage Devices

Neeti Dubey[1], **Ashok kumar Sharma**[2]

Department of Electrical Engineering, Rajasthan Technical University, Kota, India[1,2]

Abstract: The rapid use of renewable and sustainable energy sources in distributed generation system, the importance of energy storage devices forcing the researches to develop new key technologies. For continual power deliver, make greater use of renewable electricity sources, together with solar and wind. Power electronic converters are mostly connected among the different voltage buses and storage systems. Bidirectional dc-dc converter topologies are used for providing charging or discharging. This paper presents the quadratic nature for obtaining higher voltage gain ratios in step-down (buck) and step-up (boost) converter's operating states with reduced charging and discharging ripples. Proposed scheme has been developed and analyzed using MATLAB/ simulink.

Keywords: Buck converter, Boost Converter, ESD, Quadratic dc-dc converter schemes

I. INTRODUCTION

Electric power created by sustainable power sources is unsteady in nature, in this way delivering an awful impact on the utility grid [1]. The storage of energy can be possible in two ways, one is magnetically (using inductors) and another one is electrically (using capacitors) [2]. DC-DC converters change the voltage level which might be upper or lower, storing and releasing the energy at distinct voltage. Basically voltage & frequency stability can be realized by the use of such ESDs in sustainable energy sources, for example, sun-based and wind. Because of operational prerequisites of the conveyed age framework, ESDs need such type of DC-DC converters which can permit charging and discharging. The job of Energy storage gadgets in the expanding entrance of inexhaustible and maintainable vitality sources is broadly perceived. Various devices supported electrochemical energy storage systems likewise; ultra capacitor, batteries.

This paper presents traditional buck and boost quadratic converter which comprises of DC-DC boost converter with a coupled inductor for the distributed generation system [3]. Basic step-up converters give higher voltage gain but these converters face the issue due to limited reverse recovery issue of diode and power losses [4-9]. For obtaining proposed converter for higher voltage gain, two inductors and capacitors have been used [11-14].

In this article buck-boost converter has been simulated which are bidirectional in nature. These converters are very helpful in distribution generation system as conventional converters are less efficient to work in higher frequency regions. This converter is moreover depicted by a fundamental control system since it is only imperative to control one power semiconductor for each movement mode. The additional power semiconductors remain reliably on or continually off. Quadratic converter shows up with DC transformation proportion that offers an essentially more extensive change extend, persistent input and yield current, diminished charging/releasing ripple and moreover direct control hardware.

II. ELECTROCHEMICAL ESD

Electrochemical devices are basic elements of electrochemistry which are highly demanded resources that provide reliability in the solutions of telecommunication applications. These devices are basically eco-friendly in nature.

A. Supercapacitors

Super capacitor is generally used to store electrical energy in which two parallel plates separated by an insulating medium i.e. dielectric. To achieve a high value of the capacitor, electrochemical double layer capacitance or ultra capacitors used which possessed large surface area carbon electrodes. As compared to conventional capacitor, super capacitors have greater capacitance and high energy density.

B. Batteries

Batteries are mostly made up of consisting one or more electrochemical cells which obey principle of the electrochemical energy conversion. The Bidirectional nature of the DC-DC converter is responsible to flow the power from the DC-grid to the battery or vice-versa as shown in fig.1.

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Fig.1.Basic scheme of bidirectional converter

III. QUADRATIC BUCK- BOOST CONVERTER

Figure 2 and 3 show the most known topologies with wide voltage range that is step up and down converter. These topologies are characterized by the use of passive elements.

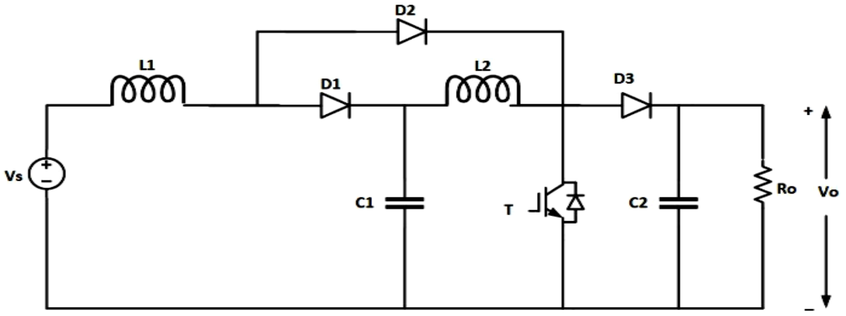

Fig.2. Traditional quadratic boost (Step-up) converter

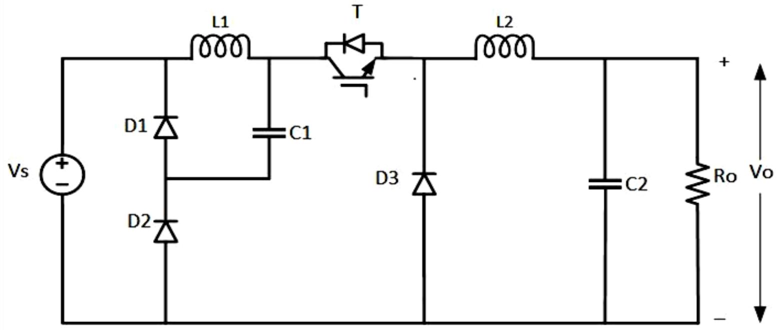

Fig.3. Traditional quadratic buck (Step-down) converter

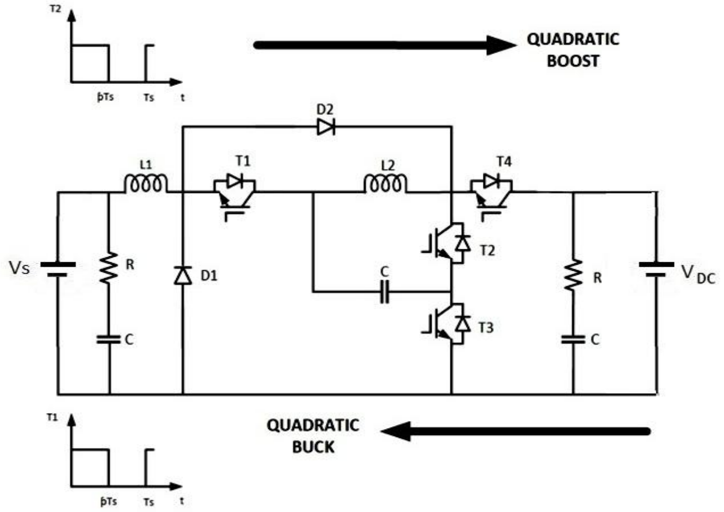

Fig.4. Proposed bidirectional quadratic buck-boost converter

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With the analysis of these previous traditional quadratic buck (step-down) converter and traditional quadratic boost (step-up) converter, it is found that these converters hold the unidirectional power flow using the extra passive elements compared to the normal power circuit, which provide the additional power losses. Individually both the converters possess uncertainty in duty ratio. These limitations are rectified by the new bidirectional quadratic dc-dc converter.

The new bidirectional buck-boost quadratic converter comprises four IGBT switches, capacitors, inductors. Additionally RC filter is connected in the input and output side of the proposed converter which reduces the output voltage spikes and minimizes the charging and discharging ripple. The quality of the proposed converter is, the only one active switch is responsible for each mode of operation.Fig.4. shows the proposed bidirectional quadratic nature buck-boost or step up-down converter.

A. Operation in Boost(step-up)Mode :

In the discharging mode transistors T_1 and T_4 are turned-off and the transistor T_3 is turned-on. The circuit operation can be split into two different phases over one half cycles as discussed below:

First phase**:** during this time T_2 is turned-on during δTs .during this time period, storage device deliver its energy to the L_1 and capacitor to the L_2, this shows the rising nature of current in both L_1 and L_2. The circuit diagram of the first phase is shown in Fig. 5 (a).

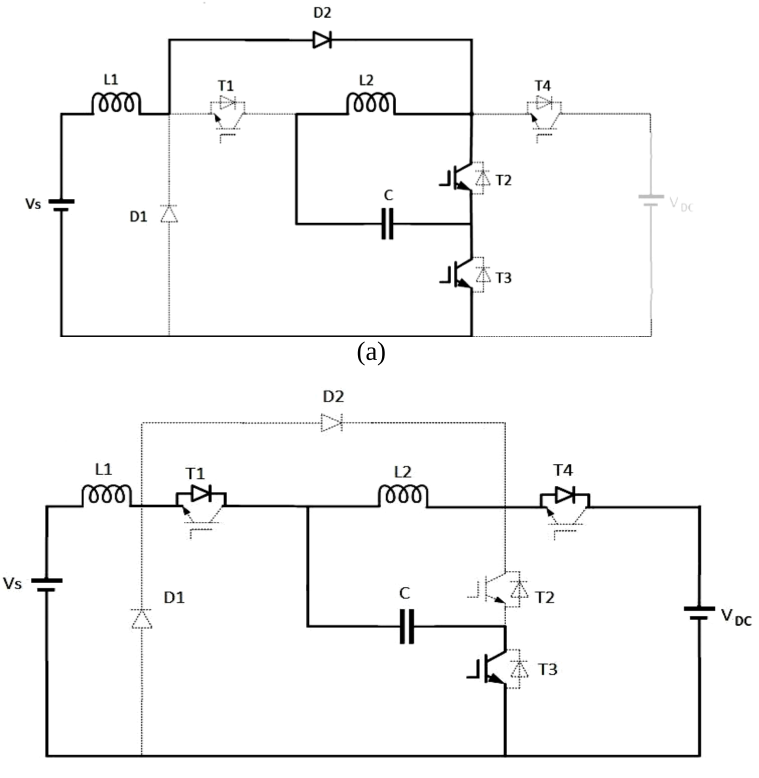
Second phase**:** In the second phase, the transistor T_2 will be turned-off in the duration of (1-δTs). In this stage, both the passive elements (L_1 and L_2) discharge. During this time-interim the inductor L_1 transferred energy to the capacitor and inductor L_2 transferred energy to the load. The circuit diagram of the second phase is shown in Fig. 5 (b).

These phases explained the voltage gain of this converter in Boost mode can be obtained. In this analysis, the average voltages of both the inductors are equal in the first and second phase, the following relationships are received:

$$\delta V_S + (1-\delta)(V_S - V_C) = 0 \tag{1}$$

$$\delta V_C + (1-\delta)(V_C - V_O) = 0 \tag{2}$$

Here, $V_O = V_{DC}$



(a)

(b)

Fig.5. Equivalent circuits during one switching period for the boost mode of the storage system.

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By the the preceding equations, the input to output voltage gain in step-up mode can be obtained from equation (3).

$$V_0(1-\delta)^2 = V_I \tag{3}$$

According to the above analysis, these two operating phases present following relationships that are

$$\frac{I_{L1}}{I_{L2}} = 1/(1-\delta) \tag{4}$$

Fig. 6 shows the operational waveform for Boost m- ode.

B. Operation in Buck (step-down) Mode:

In the charging mode of the buck converter, the energy will be transferred from the load to the storage device i.e. battery. This mode of operation is executed by the transistor T_1. Thus, the transistors T_2 and T_3 are turned-off and transistor T_4 is turned-on. Similarly the two modes of the buck converter as discussed below.
First phase: In this phase transistor T_1 is turned-on during the time interim of δTs. In this duration of time, the current will be transferred from the load to the inductor L_1 and from the capacitor to the inductor L_2 in Fig. 7 (a).

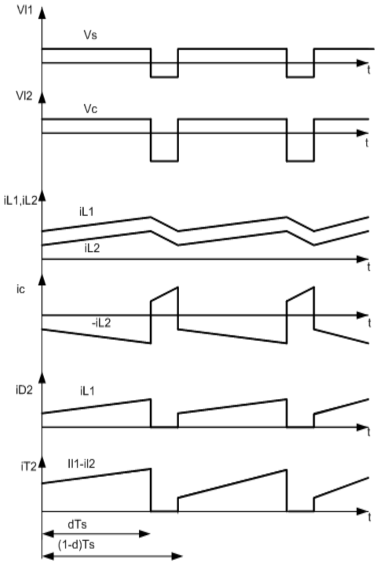
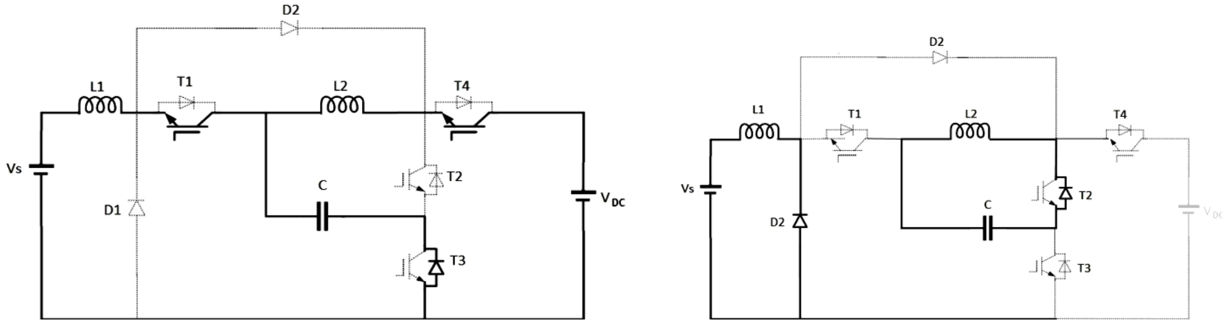


Fig.6. Operational waveforms of boost mode



(a) (b)

Fig.7. Equivalent circuits during one switching period for the charging mode of the storage system.

Second phase: In this phase transistor T_1 is turned-off in the duration of (1-δTs). Energy stored in the inductor L_1 will be delivered to the capacitor C and L_2 will now be transferred to the storage device in Fig.7.b). From the assessment of these two stages is conceivable to accomplish the voltage addition of this converter buck mode. Hence, taking into account that the normal voltages of both the inductors equal to zero, the accompanying connections are acquired.

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$$\delta(V_S - V_C) + (1-\delta)V_S = 0 \qquad (5)$$

$$\delta(V_C - V_O) + (1-\delta)V_C = 0 \qquad (6)$$

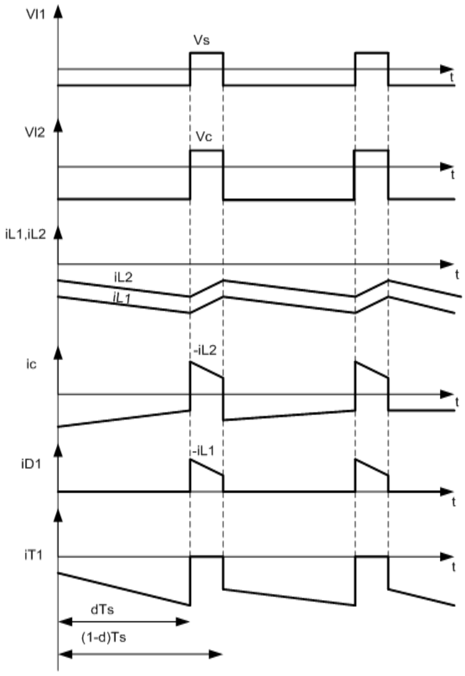

Fig. 8.Operational waveform of the proposed converter during buck mode.

$$\frac{V_o}{V_s} = \frac{1}{\delta^2} \qquad (7)$$

The operational waveforms of buck (Step-down) converter during Buck mode are shown in Fig.8.

IV. SIMULATION RESULTS

Boost mode (Forward mode): This mode shows the power stream from the ESD to the load. This simulation has been done using Matlab / Simulink platform. Fig. 9, shows the Matlab model of bidirectional quadratic dc-dc boost converter. The converter operation has been simulated for V_S = 48V (battery voltage), V_O = 180.0 V, L1 = 1.0 mH, L_2 = 2.20mH, C = 150.0 µF ,R_{in}=0.1ohm, C_{in}=47.0µF and with a switching frequency of 15 kHz. The simulated waveforms of the input & output voltage, and ripple in the inductor current as shown in fig. 12.

Buck mode (backward mode): This mode represents the power flow from the load ESD. Operating modes of the proposed bidirectional quadratic converter have been verified through numerical simulations. The simulation depicts the model of bidirectional quadratic dc-dc buck converter. Similarly, the waveforms of input voltage & current, and ripple current, voltage across transistor T_1, diode and capacitor as indicated in figure 13 and 14.

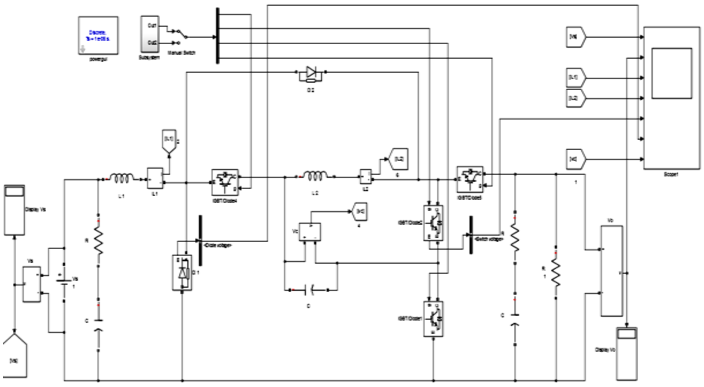

Fig.9.Simulation model of boost converter

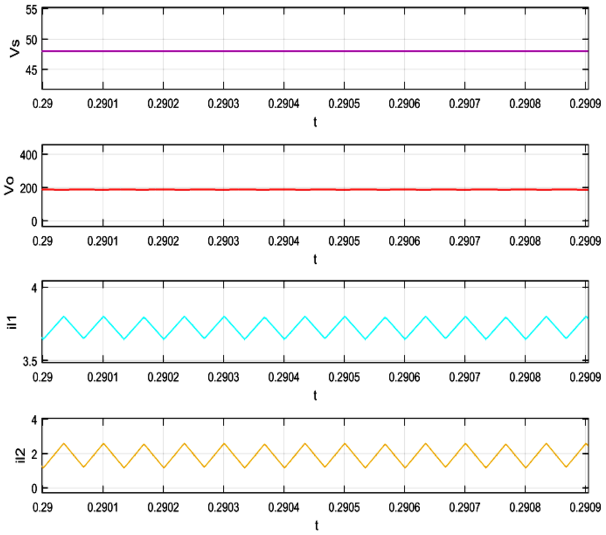

Fig. 10. Simulation waveforms of input voltage V_s, output voltage Vo, inductor current il_1, il_2 in Boost mode.

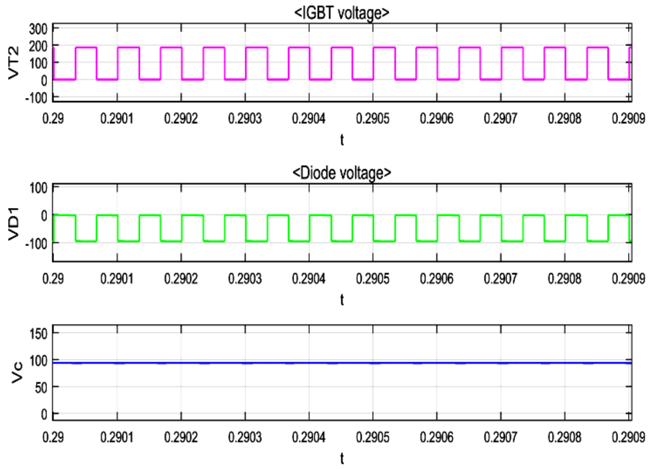

Fig. 11. Simulation waveforms of IGBT voltage V_{T2}, diode voltage $V_{D1,}$ capacitive voltage $V_{C,}$ in boost mode.

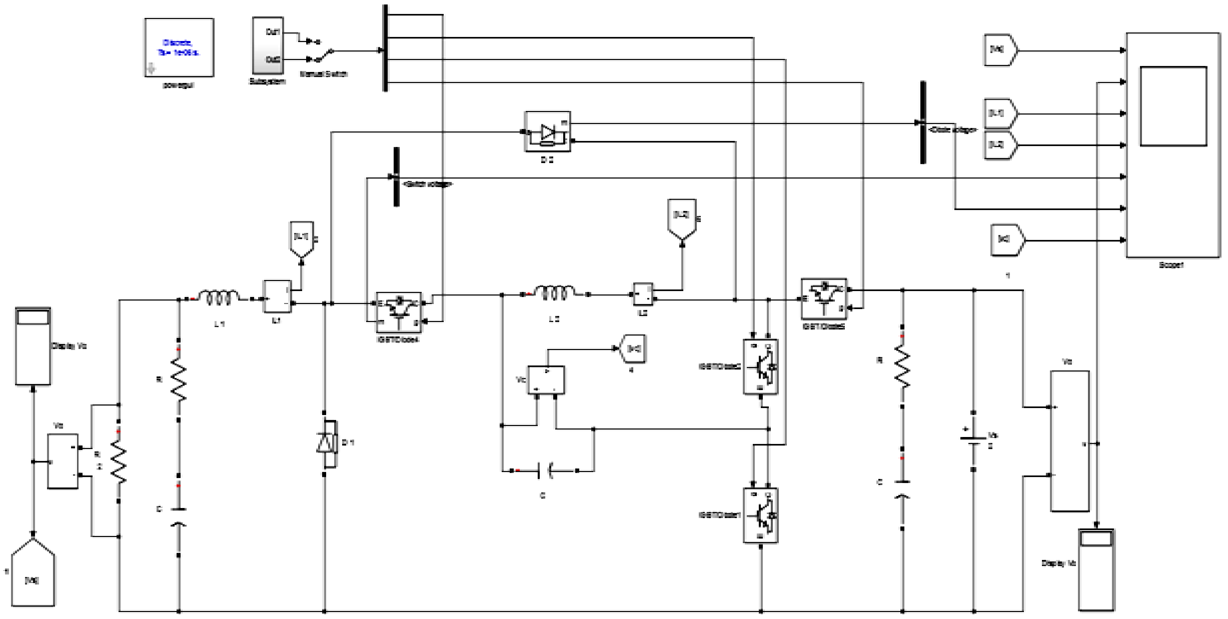

Fig.12.Simulation model of buck converter

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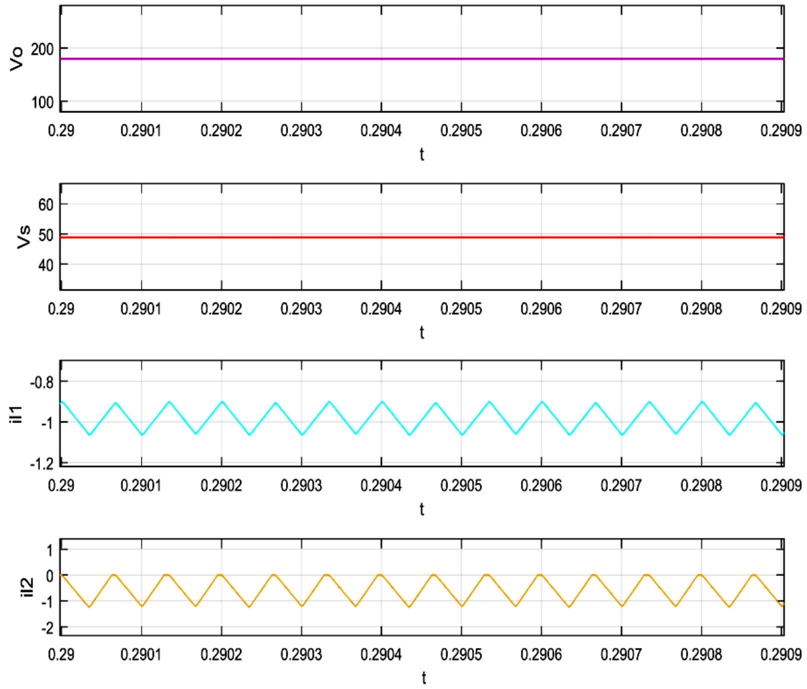

Fig. 13. Simulation results of V_s, V_O, i_{L1}, i_{L2} in buck mode.

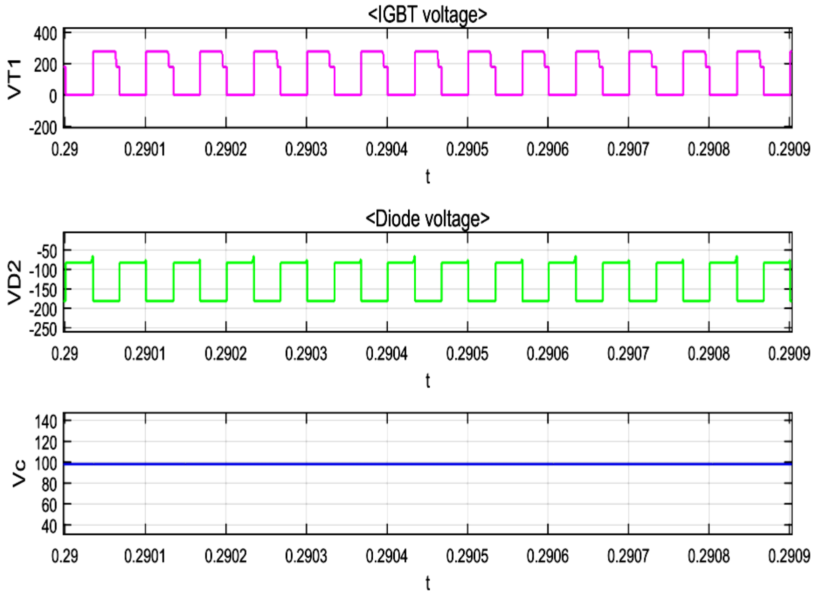

Fig.14. Simulation waveforms of IGBT voltage V_{T1}, diode voltage $V_{D1,}$ capacitive voltage V_C in buck mode.

V. CONCLUSION

The classical quadratic buck and boost converter requires extra passive elements like inductors and capacitors due to which in the case of unidirectional power flow these converters shows the uncertainty in duty cycle and many other drawbacks which make these converters less efficient. In this paper, a bidirectional quadratic buck-boost converter has been analyzed. In this analysis, different modes of charging (buck) and discharging (boost) have been explained. From the analysis, it has been evident that bidirectional DC-DC buck-boost converter provides less ripple with less component count compared to conventional quadratic buck and boost converter which make the system more compatibles for energy storage system. Here, RC filter has been introduced which reduces the spikes in the output voltage and also minimizes the charging or discharging ripple. In charging mode (buck) analysis has been done for 180v (V_{in}) and 48v (V_{out}).Similarly for discharging mode, analysis has been done for 48v (V_{in}) and 180v (V_{out}). MATLAB / Simulink platform has been used to verify the result.

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