Fall 2021 – 2022

EEE4014 – Switched Mode Power Conversion

Project Report

BI-DIRECTIONAL DC-DC CONVERTER WITH ZVT FOR ELECTRIC VEHICLES

Prepared By

19BEE1059 Pranav Kulkarni

19BEE1075 Abhinav Karmakar

VIT

Vellore Institute of Technology

(Deemed to be University under section 3 of UGC Act, 1956)

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I. Learning Objectives:

Our project is a zero-voltage transition (ZVT) bi-directional DC-DC converter for battery back-up frameworks in electric vehicles. The traditional hard switched non-isolated converter is improved with the extra auxiliary cells to achieve soft turn-on for the IGBTs. What we aspire to achieve by this is decreased switching stresses and better efficiency. The principle motive of this converter is to accomplish the activity of zero voltage transition during the communication of main switches from off to on.

II. Expected Learning Outcomes:

Our main intent is that we could make a simple bi-directional DC-DC converter with lower conduction losses and higher efficiency. This converter should be functional in high voltage applications so that it can be applied in hybrid energy storage systems used in electric vehicles.

III. Power Circuit Diagram:

Fig.1 shows the proposed topology of ZVT bi-directional DC-DC converter. The converter has two main switches (S1 and S2), a resonant inductor and capacitor (Lr and Cr), the auxiliary switches (Sa and Sb) and a output filter capacitor (Co). Let's further understand it's working.

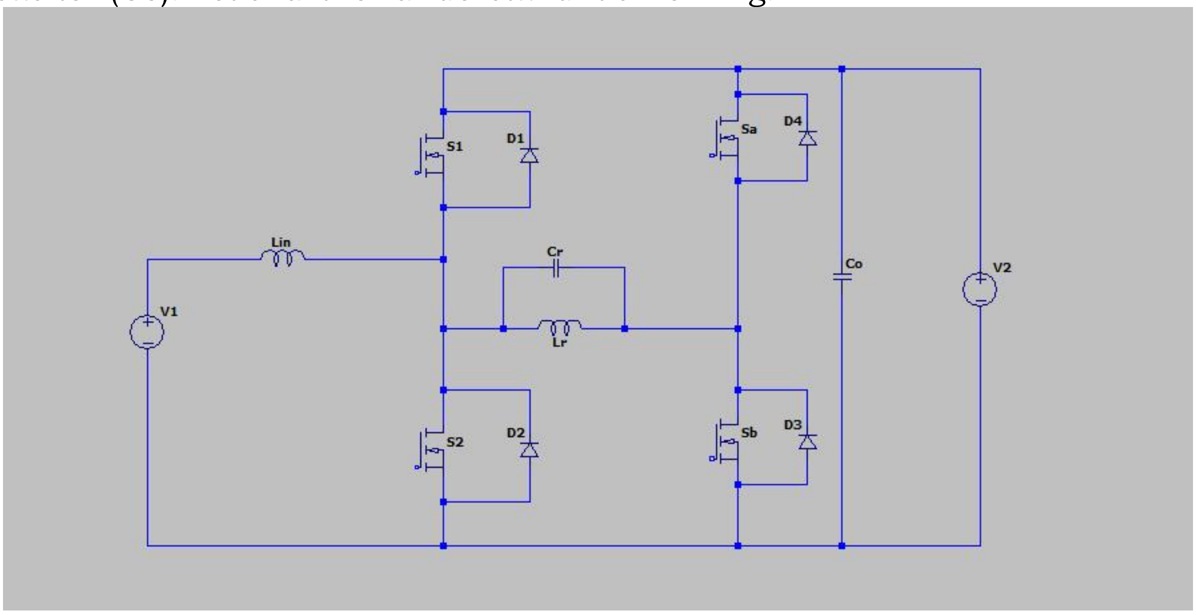

Fig 1. Proposed ZVT bi-directional DC-DC converter

(a) Boost Mode Analysis

fig.2 shows the circuit of boost mode. Initially Sb is turned on, hence current flows through Lr and Cr hence they are in resonant state. Then the resonant capacitor, Cr charges and discharges and finally falls to 0. Voltage across S2 also falls in sinusoidal and reaches zero. As voltage across Cr reaches 0, resonant current starts to flow through the anti-parallel diode of S2 for some time. Then the main switch S2 starts conducting as Cr remains 0 at this instant, Sb is turned off.

After Sb turns off, S2 the main switch continues conducting as Cr is again being charged and discharging to 0. Now, as the current flows V1, Lin and S2, Lin is charged and it stores energy. After that main switch s2 is turned off. Now at this moment all MOSFETs are off and the current directly flows through V1, Lin, anti-parallel diode of S1 and then to output Ro.

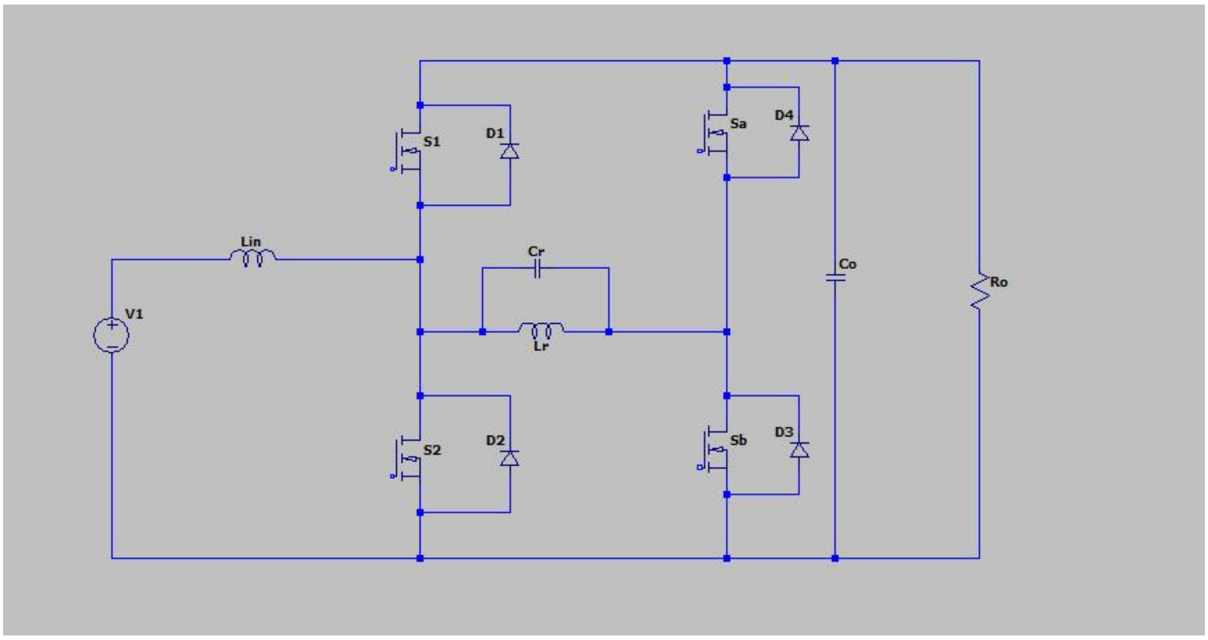

Fig 2. Circuit for the working of Boost Mode

(b) Buck Mode Analysis

Fig.3 depicts the circuit for buck mode. It works similar to it's boost counterpart. Initially, Sa is turned on hence the circuit is in resonant state with Lr and Cr active. Cr charges and then discharges ass voltage across S2 falls in sinusoidal fashion, finally reaching zero. After voltage across Cr reaches 0, current flows through anti-parallel diode of Sb to the resonant circuit to antiparallel diode of S1, before S1 switch turns on, to get soft switching.

Then, as S1 is turned on, voltage across Cr remains 0, then at this time, Sa is turned off. AsS1 continues to conduct as Cr is again being charged and discharged to. During this time, the current was flowing through anti-parallel diode of Sa. As voltage across Cr reaches 0, the output power is supplied through V2 to S1 to Lin then finally to Ro.

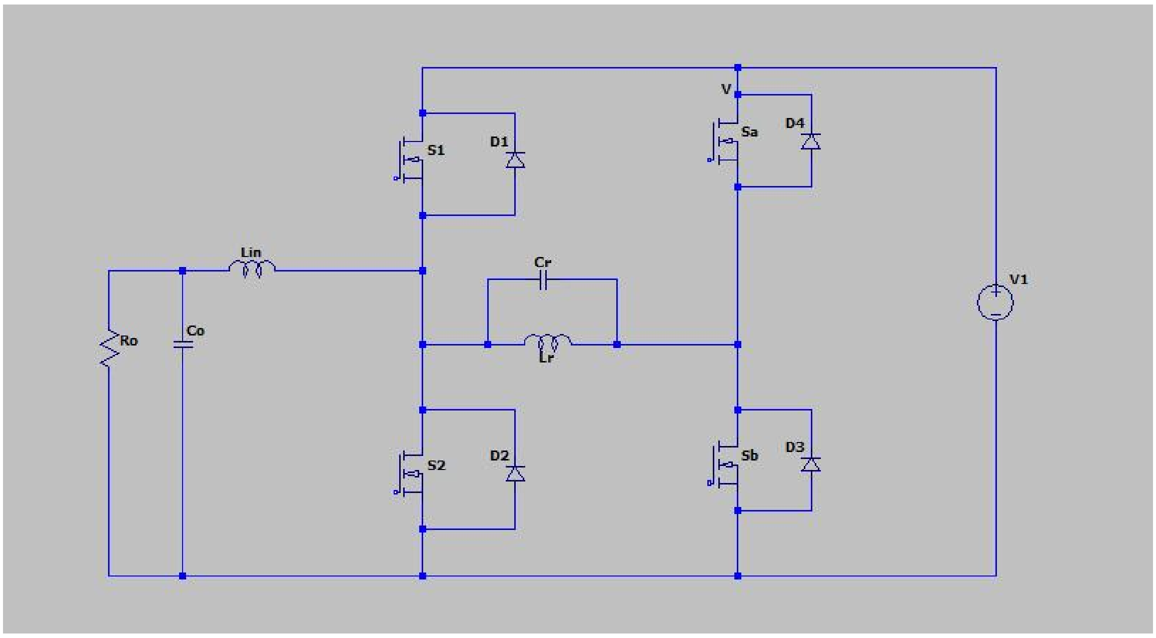

Fig 3. Circuit for the working of Buck Mode

IV. **Equations:**

For both the boost and buck mode, the input inductor current and the resonant current is given by equation (1) and (2) respectively for the initial stage

$$iL \in \frac{1}{Lr}\int_{t0}^{t1}(Vs - Vo)\,dt = \frac{1}{L\in(Vs-Vo)t+I} \quad (1)$$

$$iLr = \frac{1}{Lr}\int_{t0}^{t1}(Vo - Vs)dt = \frac{1}{Lr}(Vo - Vs)t \quad (2)$$

Vs is the voltage through source and in buck and boost mode and Vo is the output voltage. As the resonant current flows in the circuit, equations for Lin, Lr and Cr can be seen in equation (3), (4) and (5) respectively.

$$iLin = \frac{1}{Lin}Vs(t) + Is1 \quad (3)$$

$$iLr(t2) = Is1, iLr(t2) \approx Isa \quad (4)$$

$$Vcr(t) = Vo \quad (5)$$

After the auxiliary switches are turned off, and the current start to flow through the main switch, the current through the inductor is given in equation (6)

$$iLin = \frac{1}{Lin}(Vs - Vo)t + Is2 \quad (6)$$

As the output voltage (Vo) is equal to the resonant capacitor voltage (V_{cr}), hence the characteristics are expressed in equations (7), (8) and (9).

Impedance of the circuit $Z = \frac{\sqrt{Lr}}{\sqrt{Cr}}$ (7)

Resonant angular frequency is $\omega = \frac{1}{\sqrt{Lr*Cr}}$ (8)

Resonant frequency is $f_{rw} = \frac{\omega}{2\pi} = 11.1\ MHz$ (8)

V. Tables:

The design parameters for the simulation is given in table 1.

Table 1. Parameters for the simulation

SI. No.	Parameters	Symbol	Value	Unit
1.	Input voltage	V_{in}	200/400	V
2.	Output voltage	V_o	400 /200	V
3.	Input inductor	L_{in}	100	µH
4.	Resonant inductor	L_r	2	µH
5.	Resonant capacitor	C_r	10	nF
6.	Output capacitor	C_o	470	µF
7.	Output resistor	R_o	6.153	ohm
8.	Switching frequency	f_{sw}	30	kHz

Table 2. Boost Mode: parameters

SI. No.	Parameter	Value
1.	Output voltage	386.6 V
2.	Output current	62.83 A
3.	Output Power	6357.29 W
4.	Efficiency	97.5 %

Table 3. Buck Mode: parameters

SI. No.	Parameter	Value
1.	Output voltage	198.1 V
2.	Output current	32.2 A
3.	Output Power	6378.8 W
4.	Efficiency	98.2 %

VI. Experimental Results:

The ZVT bi-directional converter's simulation is performed in MATLAB Simulink individually for buck and boost mode. The simulations were performed under 30 kHz switching frequency ans 200 V and 400 V input for boost and buck mode respectively. In fig. 4 you can see the simulation circuit for boost mode. The signal is provided to S2 and Sb when working in boost mode and with a pulse width of 50 percent and 10 percent of the period respectively. Here in the boost mode, S2 is the main switch and Sb acts as the auxiliary switch.

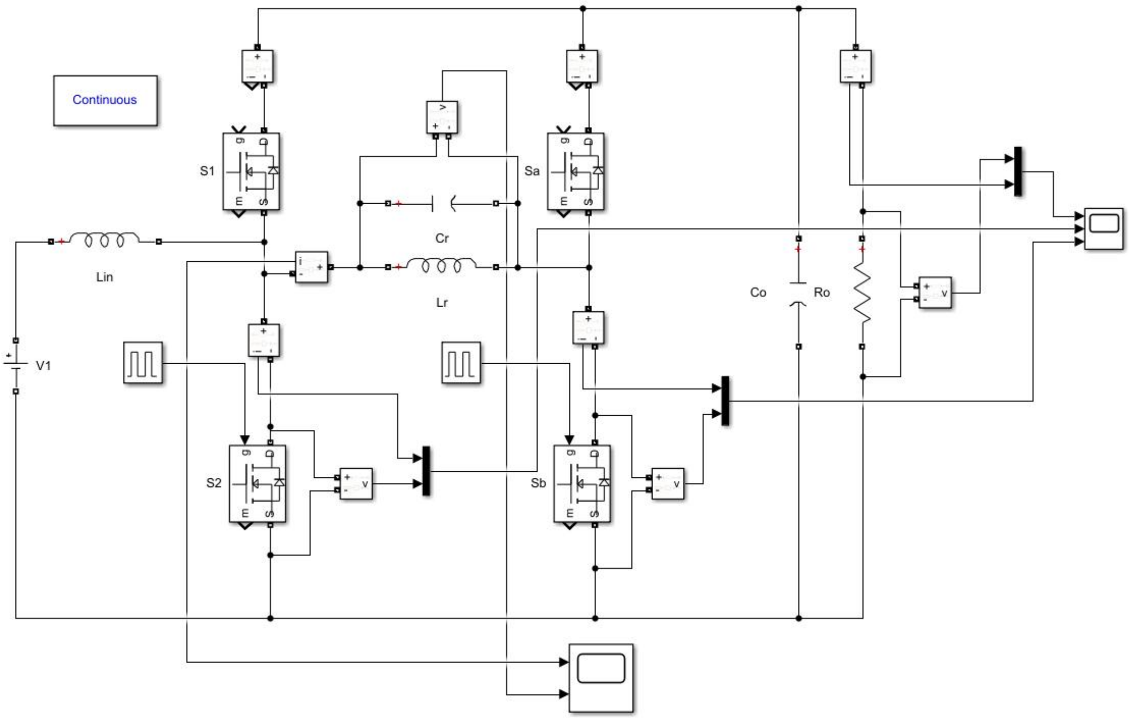

Fig 4. Simulink circuit for Boost Mode

Fig. 5 shows the simulation circuit for the buck mode operation. Here the signal is provided to S1 and Sa where S1 acts as the main switch and Sa acts as the auxiliary switch. Pulse width for S1 and Sa is 50% and 10% of the period respectively. By turning on Sa, soft switching for S1 is achieved. In Fig. 6 you can see the source-drain voltage and current across S2 and Sb while they perform under boost mode. In Fig. 8, you can see the same for S1 and Sa while the perform under buck mode. Fig. 7 and Fig. 9 shows the voltage and current across the resonant circuit (Lr and Cr) under boost and buck mode respectively. Fig. 10 shows the soft turn-on of the main switch and the auxiliary switch. Output Voltage and current is depicted in first parts of fig. 6 and fig.8 for boost and buck mode respectively. For the boost mode analysis, for 200 V input, we get a 386.6 V output and 62.83 A of output current. For buck mode, this output for 400 V of input, comes out to be 198.1 V and 32.2 A of current.

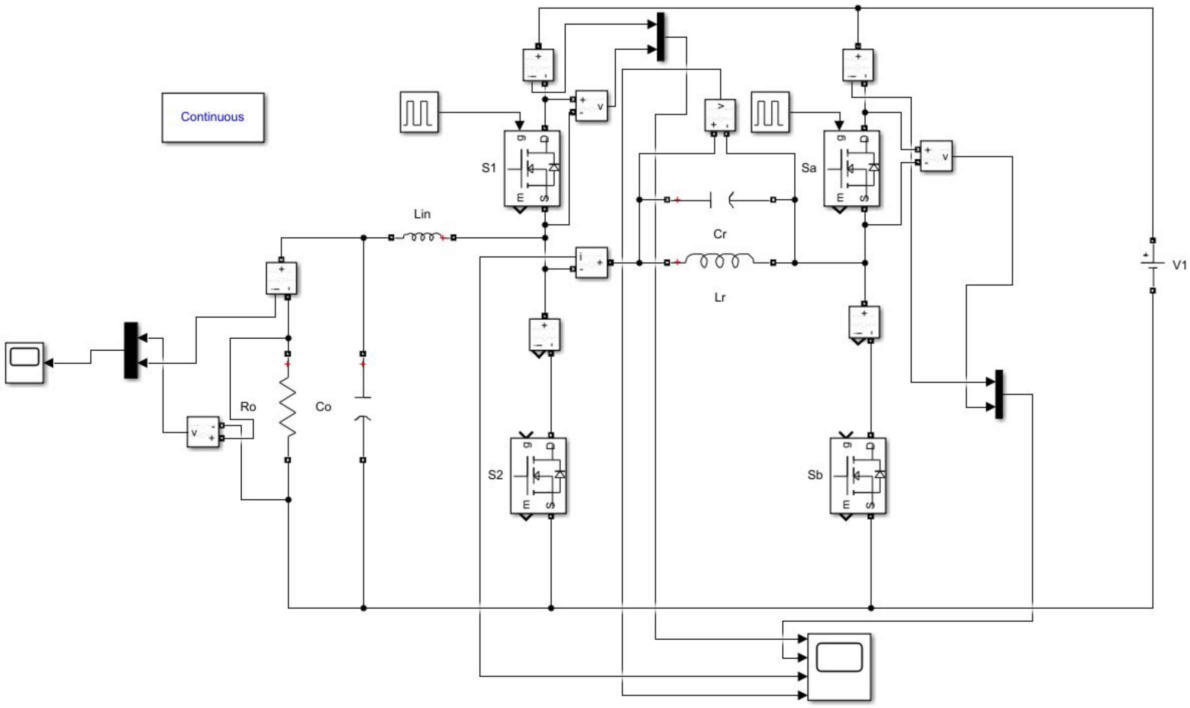

Fig 5. Simulink circuit for Buck Mode

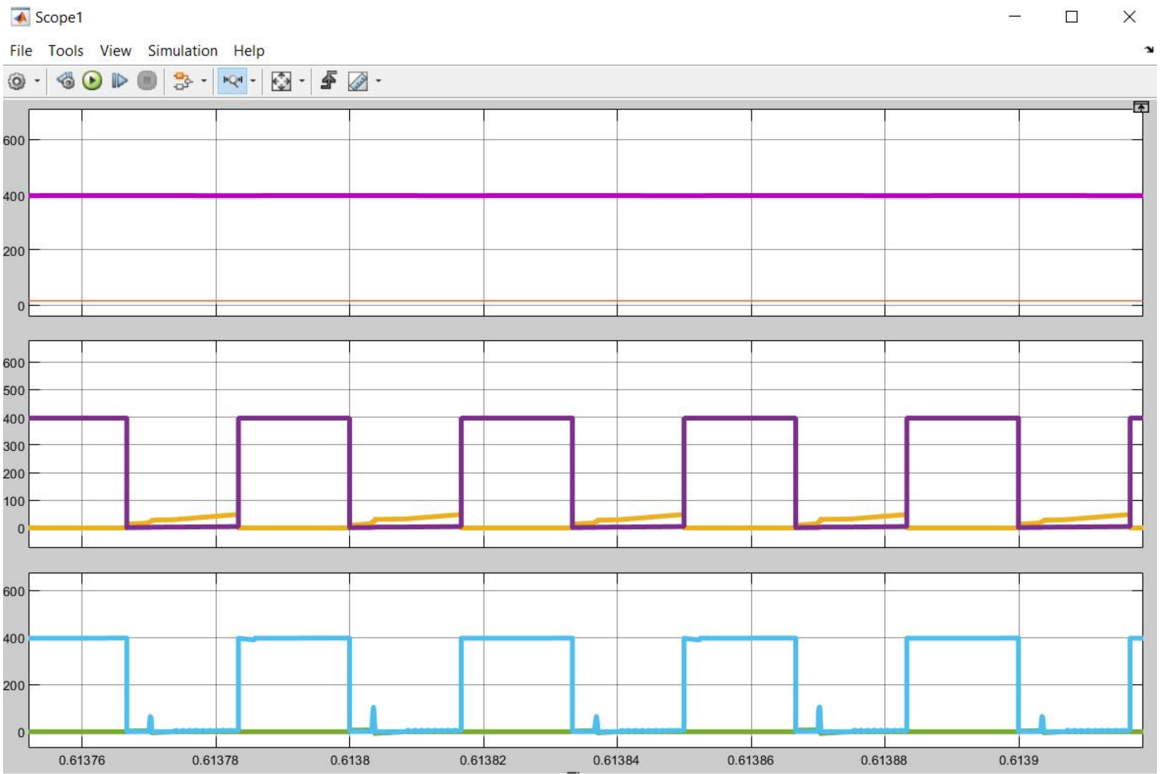

Fig 6. Boost Mode: 1st- Output voltage and Output current, 2nd- voltage & current across S2, 3rd- voltage & current across Sb.

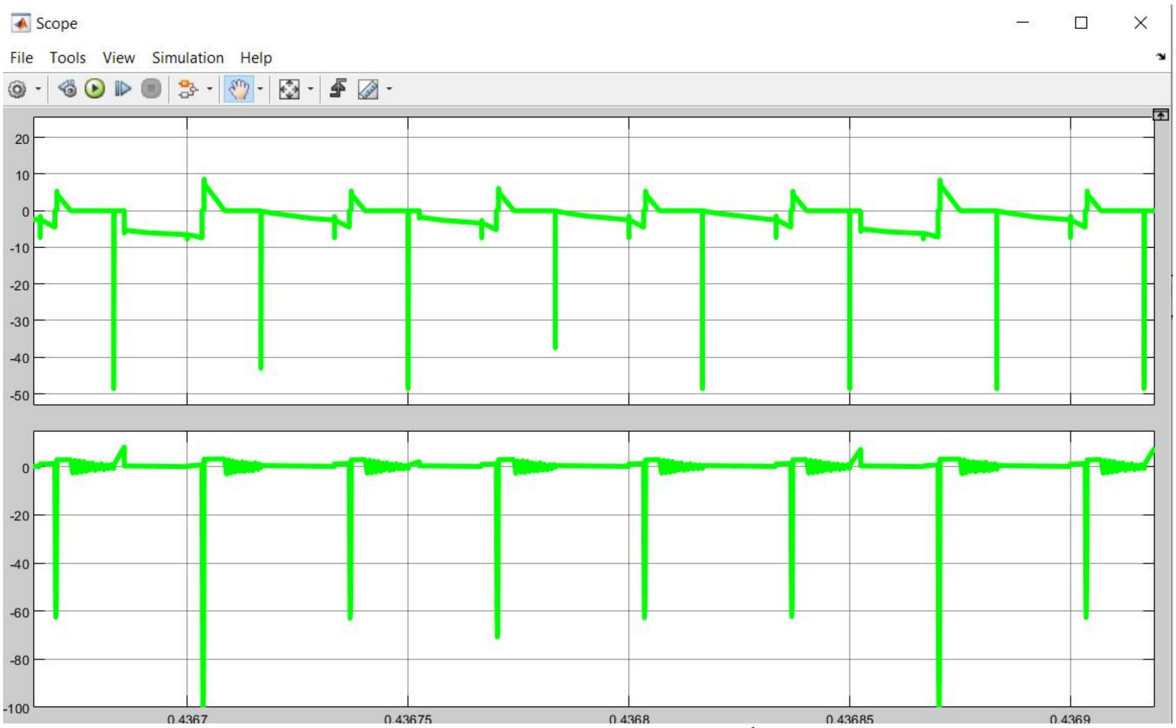

Fig 7. Boost Mode: 1st- Current across the resonant circuit, 2nd- Voltage across the resonant circuit

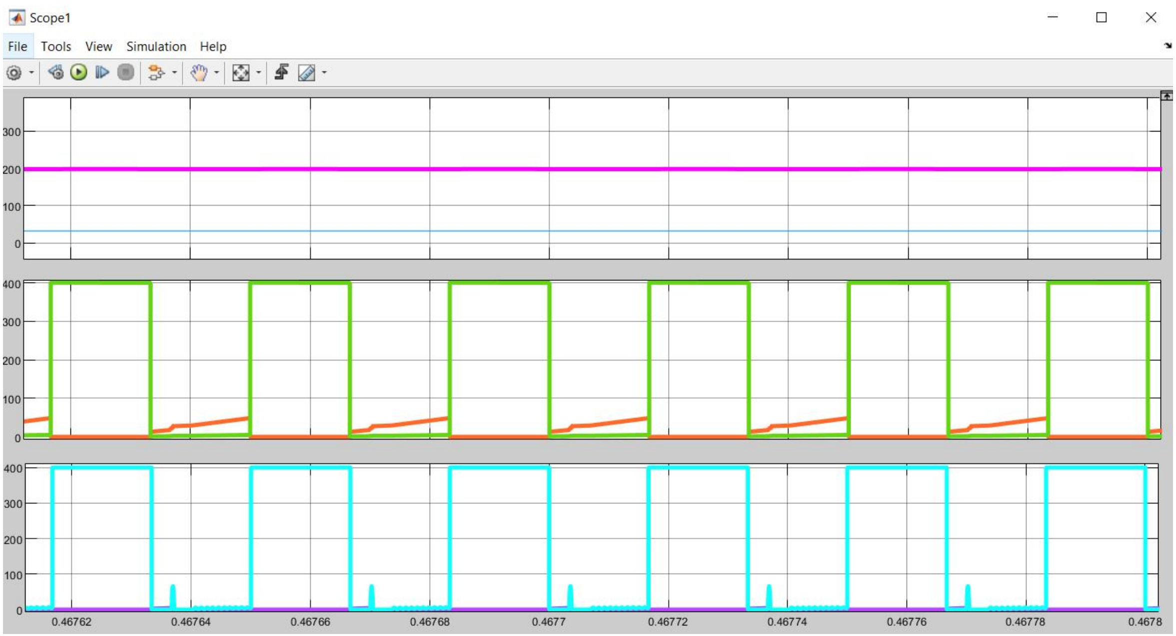

Fig 8. Buck Mode: 1st- Output voltage and Output current, 2nd- voltage & current across Sa, 3rd- voltage & current across S1.

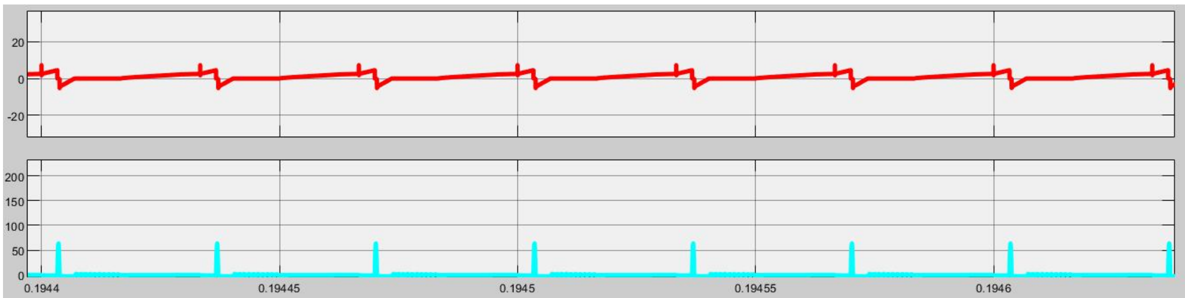

Fig 9. Buck Mode: 1st- Current across the resonant circuit, 2nd- Voltage across the resonant circuit

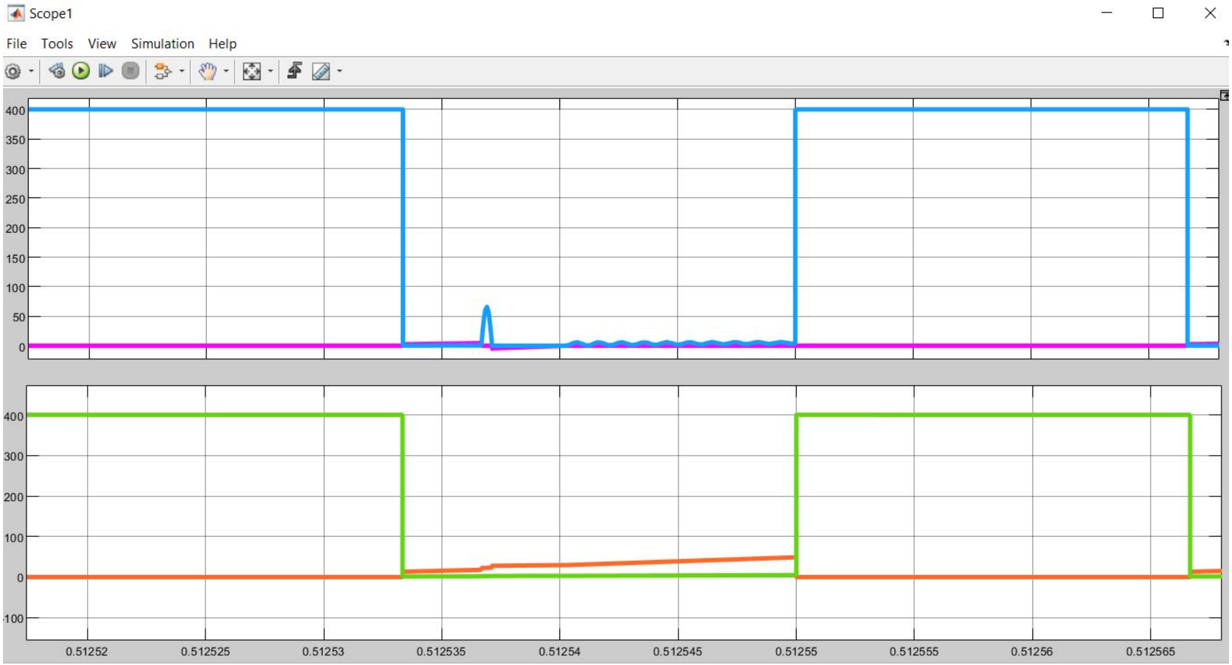

Fig 10. Buck Mode: voltage and current across S1 & Sa

VII. Conclusion:

In this project, we presented the design and simulation of a DC_DC bi-directional converter with ZVT that can be used in battery back-up applications in electric vehicles. We simulated a soft-switching non-isolated DC-DC converter with auxiliary switches and an active resonant cell. Voltage stress and current stress was reduced due to this making it suitable for the automotive applications. The simulated efficiencies were obtained around 98.2 and 97.5 for buck and boost mode operation respectively. Hence, we can say that the simulated converter has achieved reduced losses and improved efficiencies due to the soft turn-on.

VIII. References:

[1] https://www.researchgate.net/publication/319345462_Design_and_Simulation_of_a_New_ZVT_Bi-directional_DC-DC_Converter_for_Electric_Vehicles

[2] L Schuch, C Rech, HL Hey, HA Grundlinggrundling, H Pinheiro, JR Pinheiro. Analysis and Design of a New High-Efficiency Bidirectional Integrated ZVT PWM Converter for DC-Bus and Battery-Bank Interface.

[3] AP Kumar, VVSK Bhajana, P Drabek. *A novel ZVT/ZCT bidirectional DC-DC converter for energy storage applications*. International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM). Capri, Italy