Two-Quadrant Bidirectional DC to DC Converter: Simulation and Analysis for EV Application

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Abstract

The aim of this paper is to design and simulate a non-isolated bidirectional DC/DC converter which is used to charge the Electric Vehicles battery. A bi-directional DC-DC converter provides the required bidirectional power flow for battery charging and discharging based on the SoC of the battery and direction of the current flow. In this paper initially the basic behaviour of the charging and discharging module of the battery is designed to realize the behaviour of the battery as in how much constant voltage and the current is required. Analysing this data, a basic two quadrant non-isolated bidirectional DC/DC converter is simulated with constant PWM and SPWM Control techniques. The simulated non-isolated power converter topology is transformer-less, simple, low cost, light weight and has better efficiency and high reliability than isolated BDC. These converters are preferred in the high-power applications. The simulation is done using MATLAB/Simulink

Keywords: Bidirectional DC/DC Converter, Battery Charging, SPWM Techniques

1. INTRODUCTION

In the present scenario of hefty requirement of generation of electricity from renewable energy sources, and the energy storage with interfacing with the grid meant batteries has become a major challenge.[1] Energy storage meant batteries is most suitable for the renewable energy sources like solar, wind etc. A bi-directional DC-DC converter provides the required bidirectional power flow for battery charging and discharging. The duty cycle of the converter controls charging & discharging based on the state of charge of the battery and direction of the current. [2] BDCs are gaining interest because of high demand of renewable energy sources and battery-operated electric vehicles. They provide power interchange between the dc bus and energy storage system.[3]

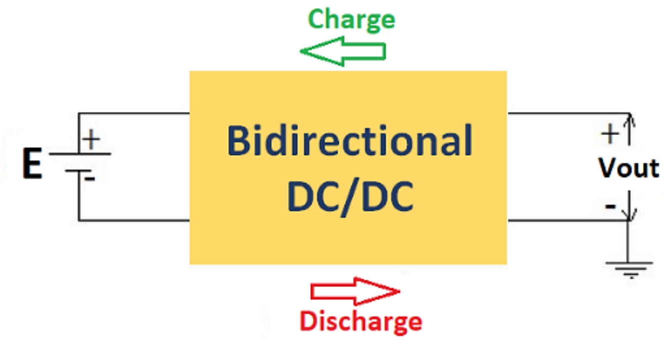

Figure 1.1. Concept of Bi-directional DC/DC converters

Bidirectional dc–dc converters allow transfer of power between two dc sources, in either direction. Due to their ability to reverse the direction of flow of current, and thereby power, while maintaining the voltage polarity at either end unchanged, they are being increasingly used in applications like dc uninterruptible power supplies, battery charger circuits, telecom power supplies and computer power systems.[4]

2. BATTERY CHARGING BEHAVIOUR

To realize the behaviour of the battery simple battery charging module is considered and shown in the Figure.2.1 for 24 V,10 Ah, Lithium-Ion Battery, thus this parameter will be helpful enough to realize the total constant voltage and current required for charging the battery also the replica of the same on the SOC of the battery. The initial and nominal SOC is kept 50%, during the initial battery charging the graph shown in Figure.2.1 is the rising slope w.r.t the charging time.

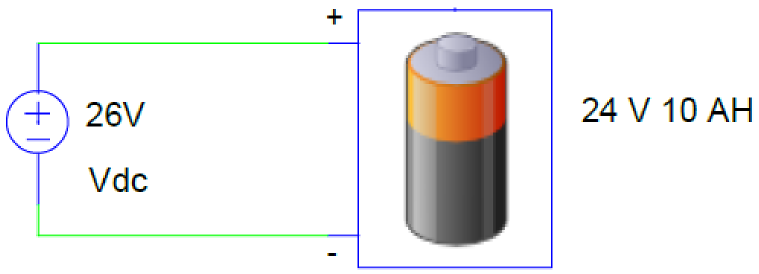

Figure 2.2. 24 V,10 Ah, Lithium-Ion Battery Charging Behavior

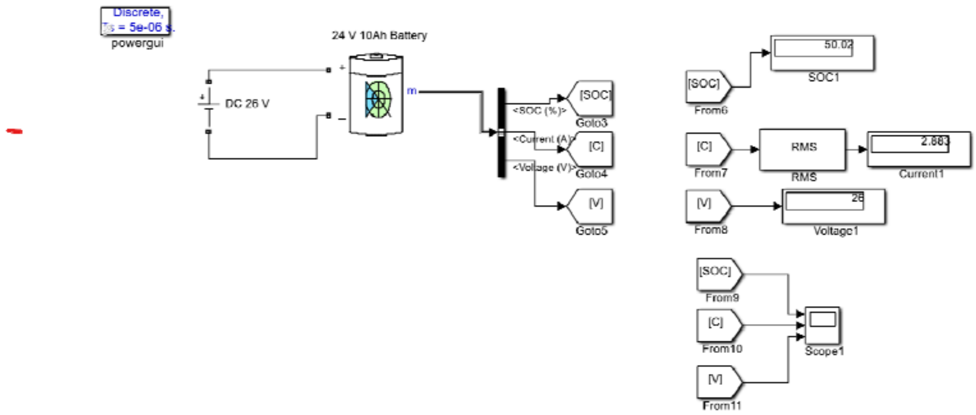

Figure 2.3. Simulation of 24 V,10 Ah, Lithium-Ion Battery Charging Behavior.

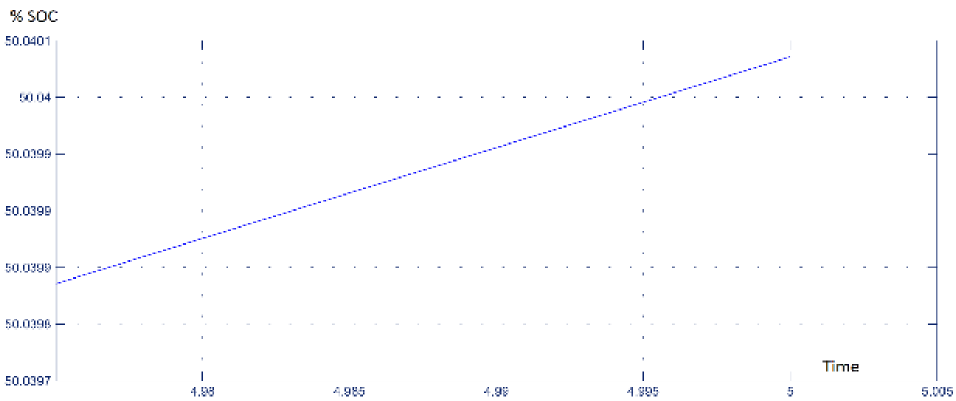

Figure 2.4 %SOC vs Time- Charging

Input Voltage	SOC (in %)	Current (in amp)	Time (in sec)
26	50.8	2.88	10
26	53.12	2.87	405
26	55.16	2.68	727
26	57.79	2.54	1047
26	60.54	2.25	1614

Table 2.1 CHARGING CHARACTERSTICS COMPARISOINS

Thus, this module gives the clarity that when the constant volage at-least 10% higher than the nominal voltage of the battery and the constant current the battery will then be able to charge at a stimulated duration. Hence to charge for 10% this module takes 26.9 mins.

3. BATTERY DISCHARGING BEHAVIOUR

The module shown in Figure.3.1 is the Battery discharging module. The initial and nominal SOC is kept 50%, during the initial battery charging the graph shown in Figure.2.1 is the rising slope w.r.t the charging time.

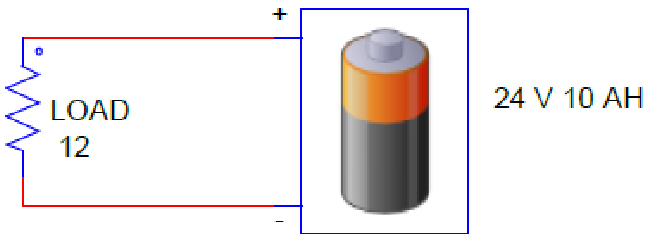

Figure 3.1 24 V,10 Ah, Lithium-Ion Battery Discharging Behaviour

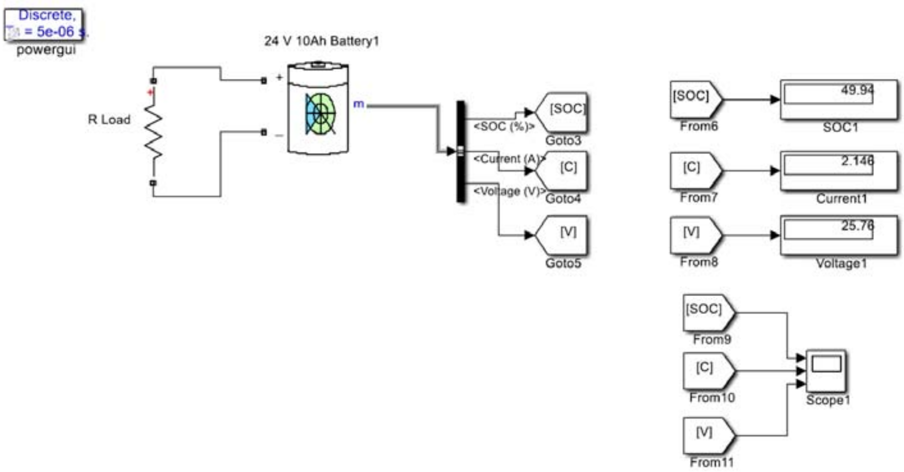

Figure 3.2 Simulation of 24 V,10 Ah, Lithium-Ion Battery Discharging Behaviour.

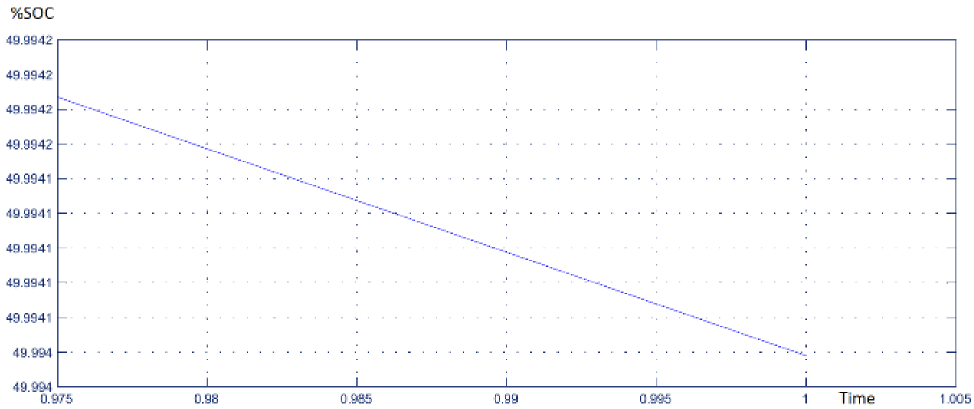

Figure 3.3. %SOC vs Time- Discharging

R Load	SOC (in %)	Current (in amp)	Time (in sec)
12 Ω	49.93	2.57	10
12 Ω	46.78	2.57	450
12 Ω	43.70	2.56	880
12 Ω	41.72	2.56	1160
12 Ω	40.00	2.56	1400

Table.3.1 discharging characteristics comparisons

In the discharging module the battery is getting used by the R load of 12 Ω, and the rating of the battery is 24 V 10Ah, hence the discharging for 10% is 23.3 minutes. A bi-directional DC-DC converter provides the required bidirectional power flow for battery charging and discharging. The duty cycle of the converter controls charging and discharging based on the state of charge of the battery and direction of the current.[1]

4. Two - QUADRANT BIDIRECTIONAL DC/DC CONVERTER (PWM)

This circuit is used in the project as such to provide both the charging and the discharging options together through the buck and the boost operation.

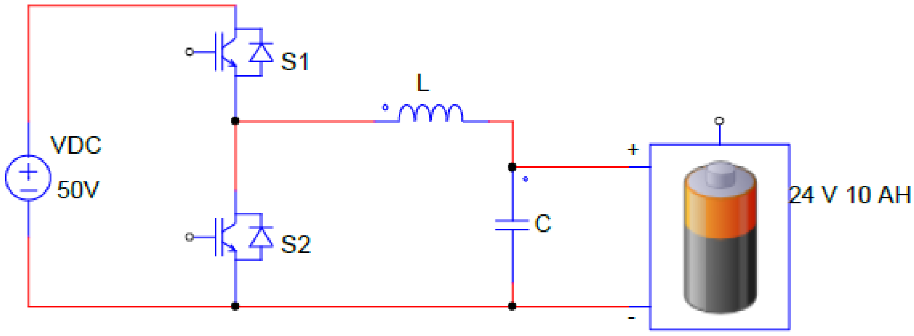

Figure 4.1. Basic Non-isolated Bidirectional Converter

The basic 2 quadrant bi-directional DC-DC converter is simulated with normal PWM technique.

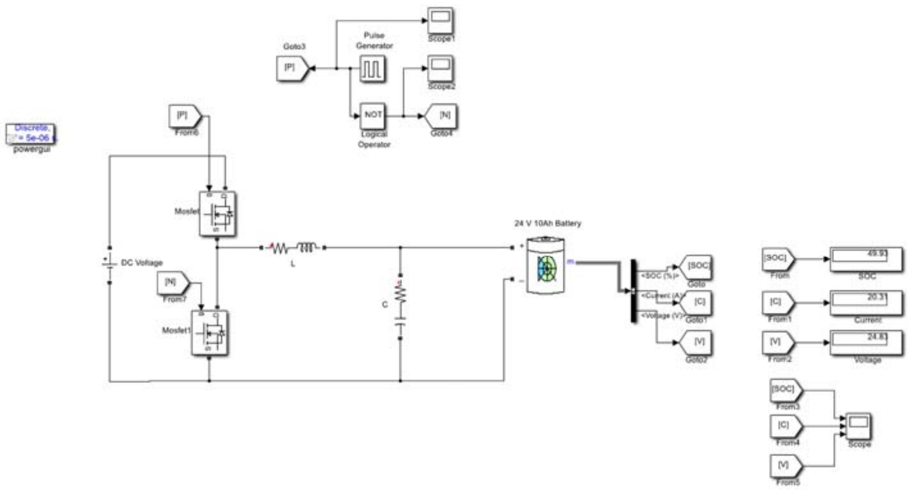

Figure 4.2. Simulation of 24 V,10 Ah, through basic non-isolated bidirectional converter

A. Buck mode (Forward Operation/Charging):

In Buck mode, the output voltage is less than the input voltage. To charge the battery from the DC input voltage, switch S1 is triggered and S2 is kept off as shown in Figure. 4.1 When switch S1 is ON, the input current rises and flows through S1 and L. When S1 is OFF, the inductor current falls until the next cycle. The energy stored in inductor L is supplied for charging the battery.[2]

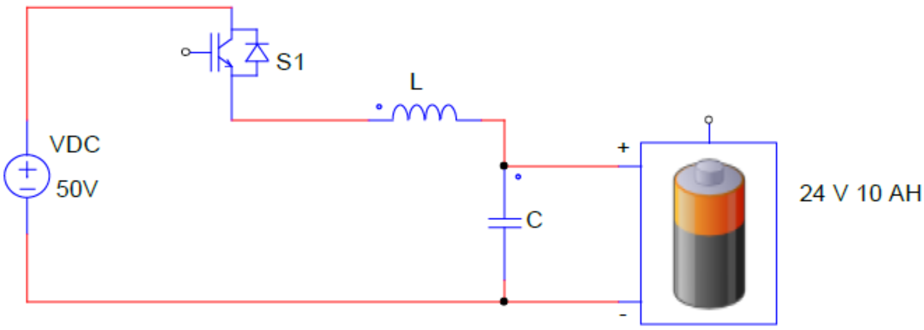

Figure 4.3. Buck Mode Operation.

The DC voltage is assumed to be 51 V and battery voltage is 24 V The design of Buck converter is as shown below:

i) Duty cycle

The duty cycle of the switch with estimated efficiency of 95% is given by equation.

$$D = \frac{Vout}{Vin * \eta} = \frac{24}{50 * 0.9} = 0.54$$

Input Voltage	SOC (in %)	Current (in amp)	Time (in sec)
50	50.8	6.88	90
50	53.12	6.87	140
50	55.16	6.68	370
50	57.79	7.54	419
50	60.54	7.25	465

Table 4.1. charging characteristics (BDC- PWM)

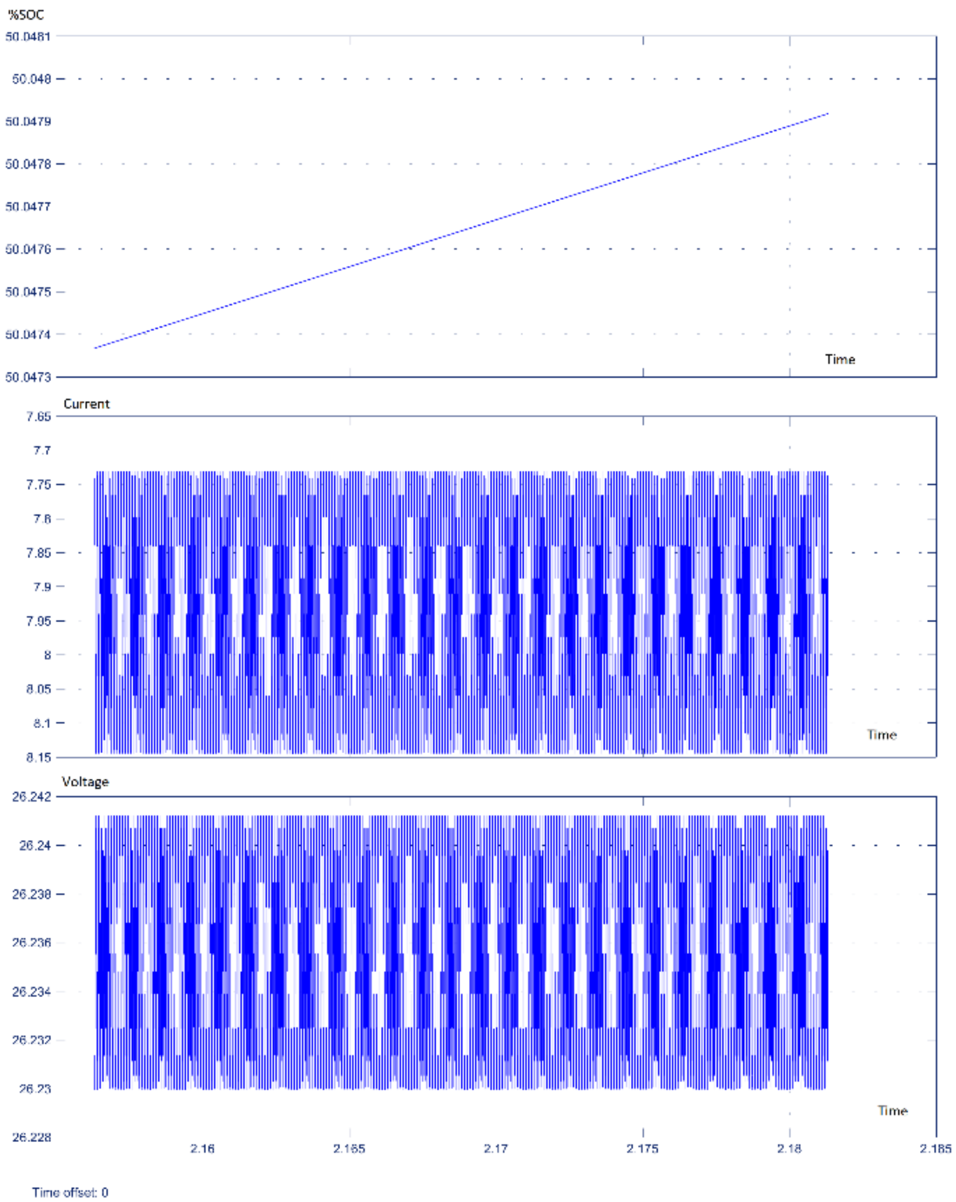

Figure 4.4. Simulation of 24 V,10 Ah, through basic non-isolated bidirectional converter.

The Figure 4.4 Shows the graph of discharging in buck mode. In the discharging module the battery is getting used and the rating of the battery is 24 V 10Ah, hence the discharging for 10% is 7.73 minutes.

B. Boost mode (Backward Operation/Discharging)

In Boost mode, the output voltage is more than the input voltage. The battery discharges power to the load with switch S2 is triggered and S1 is off. The operation of this mode is shown by Figure 4.1. When switch S2 is ON, the input current rises through inductor L and S2. When S2 is OFF, the inductor current falls until the next cycle. The energy stored in inductor L flows through the load.[2]

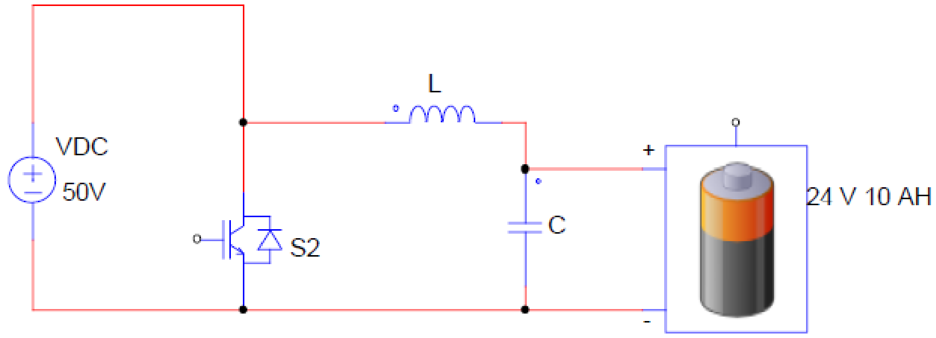

Figure 4.4. Boost mode operation.

$$D = 1 - \frac{\text{Vin} * \eta}{\text{Vout}} = \frac{50 * 0.9}{24} = 0.54$$

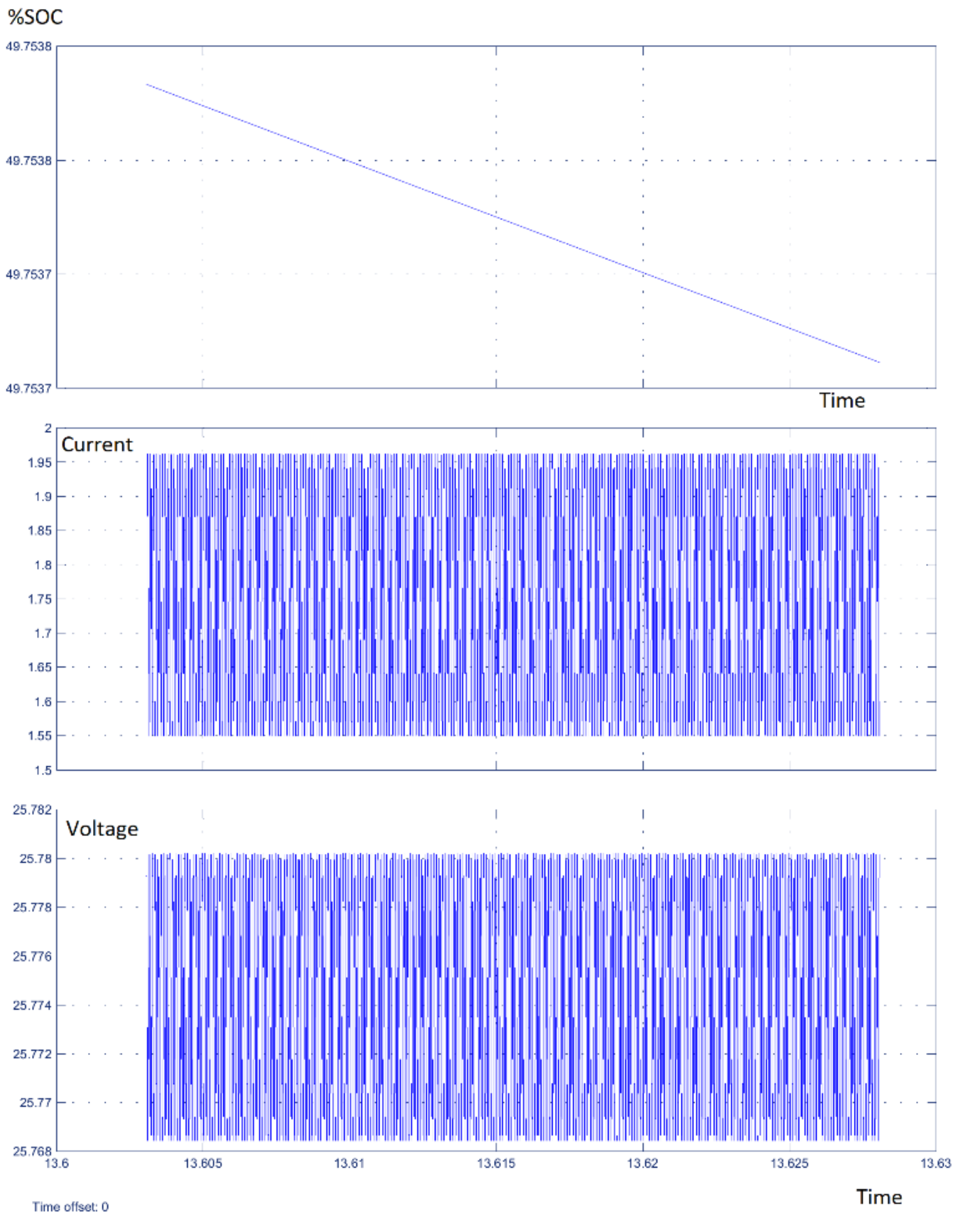

Figure 4.5. Simulation of 24 V,10 Ah, through basic non-isolated bidirectional converter

Input Voltage	SOC (in %)	Current (in amp)	Time (in sec)
50	50.8	3.8	90

50	45.6	3.7	140
50	43.70	3.71	622
50	41.72	3.6	809
50	40.00	3.5	905

Table 4.2 discharging characteristics (BDC-PWM)

The Figure 4.5 Shows the graph of charging in boost mode. In the discharging module the battery is getting used and the rating of the battery is 24 V 10Ah, hence the discharging for 10% is 15.73 minutes.[12]

5. Two QUADRANT BIDIRECTIONAL DC/DC CONVERTER (SPWM)

The Sinusoidal PWM (SPWM) control is the most efficient PWM Control Technique, the sinusoidal AC voltage reference is compared with the high-frequency triangular carrier wave in real time. After comparing, the switching states for each pole can be determined based on the following:[12]

- Voltage reference > triangular carrier: upper switch is ON
- Voltage reference < triangular carrier: lower switch is ON.

The same comparison is shown in Figure 5.1 The sinusoidal waveform is compared with the repetitive triangular carrier waveform of a switching frequency of 10kHZ.

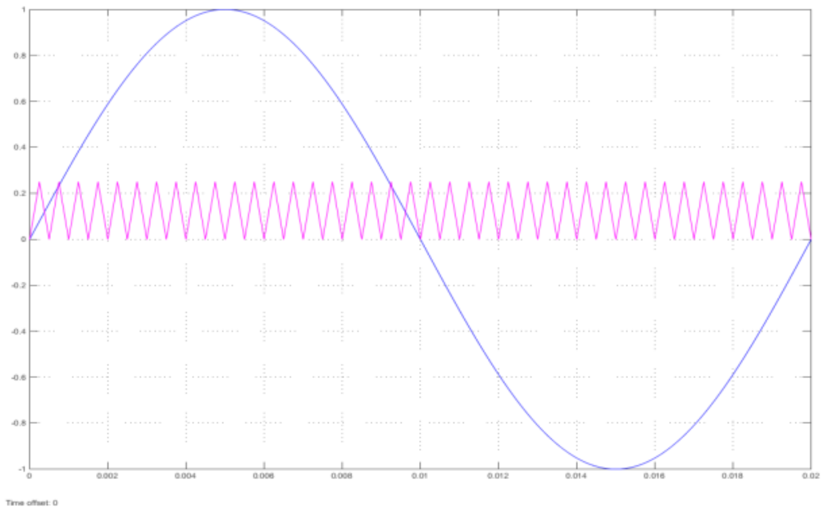

Figure 5.1. SPWM Career Signal Comparison (POD)

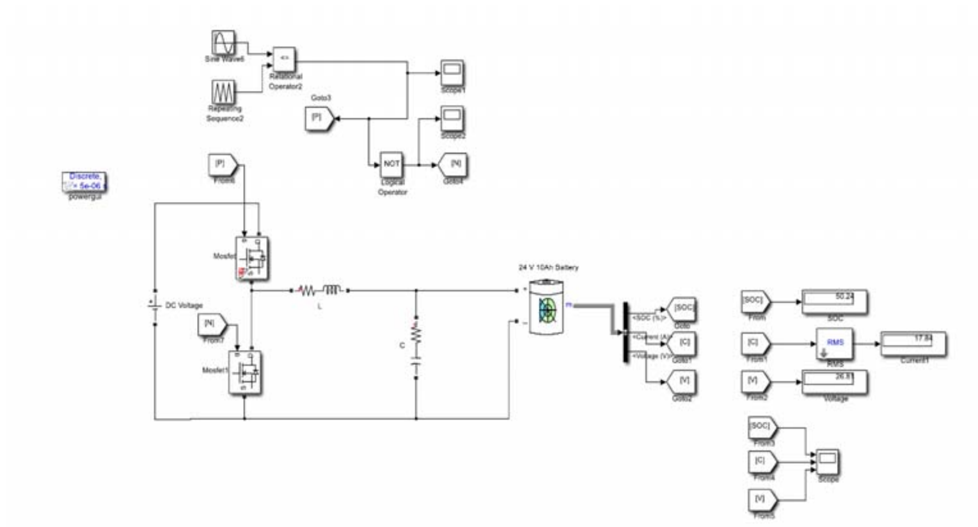

Figure 5.2. Simulation of 24 V,10 Ah, through basic non-isolated bidirectional converter (SPWM Control).

Finally, the various comparisons are done for the type of control techniques used in the circuit. Hence this clarifies that the SPWM control technique will definitely save the effective time in charging. This can be further helpful for charging the battery. [12]

Type of Control	SOC (in %) for 10%	Mode	Time (in sec)
PWM	50.8 to 60.54	Charging	465
SPWM	50.12 to 60.81	Charging	358
PWM	50.3 to 40.14	Discharging	905
SPWM	50.3 to 40.14	Discharging	1204

Table 5.1 Comparisons of different control techniques

Switching Device	IGBT
Input Voltage	50 volts (D.C)
Output Voltage	26 volts (D.C)
Output Current	1.9 Amp
Output Power	49.4W
Switching Frequency	10kHz

Capacitance	1000µF
Magnetizing Inductance	1mH

Table 5.2. Circuit parameters of the dc-dc converter (PWM)

6. CONCLUSION

In this paper the basic behaviour of the charging and discharging module of the lithium-ion battery is designed and simulated to understand and to realize the battery response as in how much constant voltage and the current is required.

Analysing this data, a basic two quadrant non-isolated bidirectional DC/DC converter is simulated with constant PWM and SPWM Control techniques. The reading of the simulation is than compared for determination of faster response from the SPWM technique. This paper will be helpful for researchers and scholars in the field of battery charging and battery management system for EV's

7. REFERENCES

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