Simulation of Bidirectional Battery Charger Circuit using Buck/Boost Converter in Simulink

MD. Maruful Islam
Department of Electrical Electronics
And Communication Engineering
Military Institute of Science
And Technology
Dhaka, Bangladesh
mdmarufulislam740@gamil.com

Md. Galib Hasan
Department of Electrical Electronics
And Communication Engineering
Military Institute of Science
And Technology
Dhaka, Bangladesh
hasangalib93@gamil.com

Md. Mobin Khan
Department of Electrical Electronics
And Communication Engineering
Military Institute of Science
And Technology
Dhaka, Bangladesh
mobin.ovi987@gamil.com

***Abstract*—This project presents a bi-directional battery charger circuit controlled by a PI controller. The DC to DC converters play a key role in solar power plants, battery charging stations, and electrical vehicles. This bi-directional DC to DC converter allows for both charging and discharging of batteries. It functions as a boost converter during discharging and as a buck converter when charging. The bi-directional converter is controlled by a closed-loop PI controller. The simulation results of this paper are verified using Simulink software during both charging and discharging modes, and the results reached the reference values.**

***Keywords*—Battery, DC-DC Converter, Current, Voltage, Buck Converter, Boost Converter, PI Controller**

I. Introduction

Authors in [1] presented two different bidirectional converters: a cascaded step-down and step-up converter with capacitors in the middle, and a cascaded step-down and step-up converter using an inductor in the middle. These converters are designed for electrical and hybrid vehicles. Reference [2] proposed a bidirectional DC-DC converter for electrical vehicle applications during charging and discharging operations. This converter allows for step-up and step-down with zero voltage switching. Authors [3] presented a DC-DC converter for electric vehicles regarding charging modes. To improve efficiency and reliability, the DC-DC converter plays a significant role in balancing electric vehicles during charging and discharging operations.
In this project we are implementing a PI control algorithm to manage the charging and discharging processes. This includes techniques such as Pulse Width Modulation (PWM) and feedback control to ensure efficient operation and promote battery health. Utilizing simulation tools such as Simulink to model the behavior of the charger under various operating conditions. Analyzing performance such as charging and discharging voltage, current and SOC(state of charge).

II. Bi-directional Battery Charger Circuit

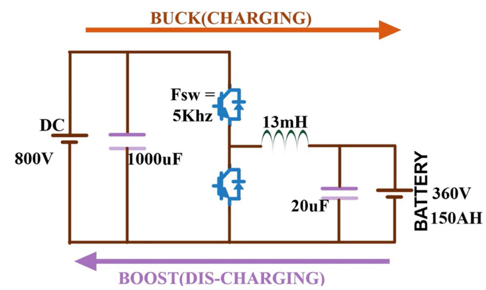

Fig. 1. Bidirectional battery charger circuit

The bidirectional DC-DC converter is shown in fig.1. The presented topology has a single voltage source, a bus capacitor,LC filter circuit, battery, and two MOSFET switches.

$$L = \frac{V_{out} \times (V_{in} - V_{out})}{I_{ripple} \times F_{sw} \times V_{in}} \tag{1}$$

$$C = \frac{I_{ripple}}{8 \times F_{sw} \times V_{ripple}} \tag{2}$$

Here,
L is the filter inductance and C is the filter Capacitance

A. Battery Charging Operation (buck converter)

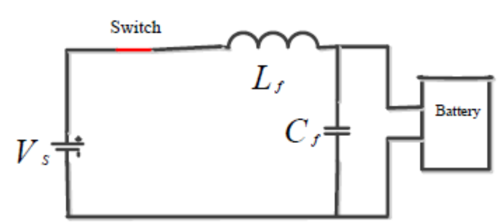

Fig. 2. MODE-I operation buck converter

The buck converter's mode-I functioning is seen in Fig. 2. The buck converter's mode-I functioning is seen in Fig. 2. In this state, S1 is turned ON, S2 is turned OFF, and both diodes are turned off. Fig. 3 depicts the buck converter's Mode-II

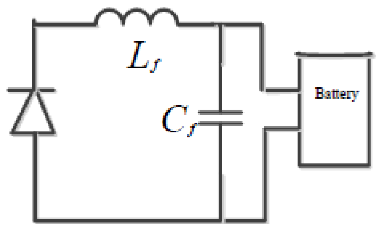

Fig. 3. MODE-II operation buck converter

operating in this mode; both switches turn off Switch 1 and 2. Diode D2 is turned on and diode 1 off.

$$V_0 = \frac{t_{\text{on}}}{T} V_s \quad (3)$$

$$V_0 = DV_s \quad (4)$$

Equation (3) and (4) represents the output voltage of the buck converter. The output voltage V0, supply voltage VS, Total time T; switch on time ton, D represents duty cycle. Figure 4

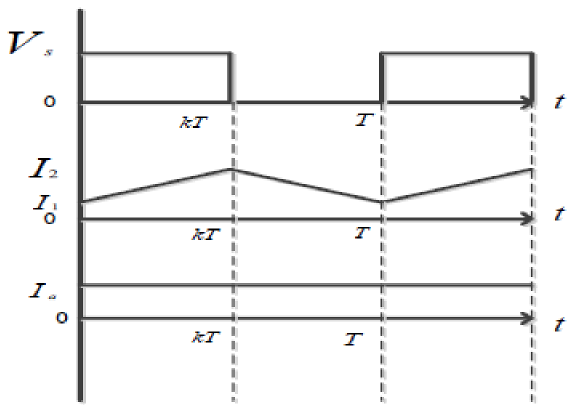

Fig. 4. Battery Charging Mode Waveforms

illustrates the output waveforms during the battery charging mode. The waveforms indicate V_s, the mean input supply voltage, while I_1 and I_2 represent the minimum and maximum currents, respectively. The output current is denoted as I_0. In the output waveforms during Mode I operation, the time range is from 0 to kT, during which the input voltage is connected to the load. In this phase, the inductor current rises from I_1 to I_2, while the output current remains constant. In Mode II operation, the supply voltage drops to zero, causing the inductor current to decrease from I_2 to I_1, with the output current still maintained at a constant level.

B. Battery Discharging Operation (boost converter)

Figure 5 demonstrates Mode III operation, in which the battery is in the discharging phase. During this mode, switch S1 is turned off while switch S2 is activated, resulting in diodes D1 and D2 being turned off as well. The current discharging from the battery passes through an inductor. Figure 6 illustrates Mode IV operation of a boost converter. In this mode, the battery current flows through the inductor,

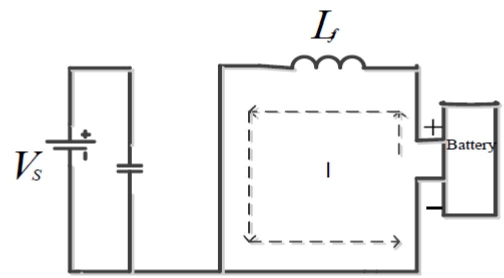

Fig. 5. MODE-III operation boost converter

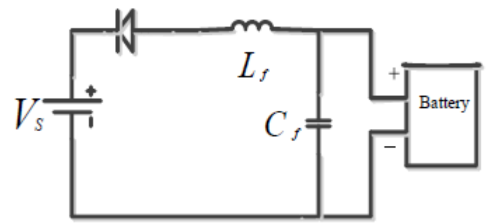

Fig. 6. MODE-IV operation boost converter

diode, and supply during discharging.

Boost converter output voltage

$$V_0 = \frac{1}{1-D} V_s \quad (5)$$

Equation (5) represents the boost converter output voltage. Fig.7 shows battery discharging mode waveforms, during 0

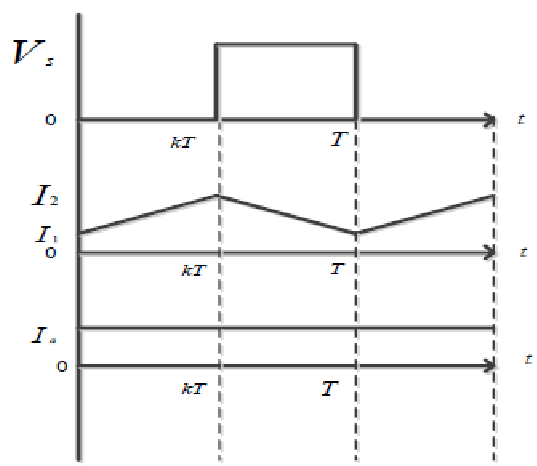

Fig. 7. Battery Discharging Mode Waveforms

to kT supply voltage turns off, the inductor current increases from minimum to maximum. This mode battery is discharging.

III. CONTROL SCHEME

Proportional integral (PI) based PWM Generator implemented for controlling Bidirectional battery charger circuit using buck/boost converter. The comparator compared the Reference current and original current, the output of the

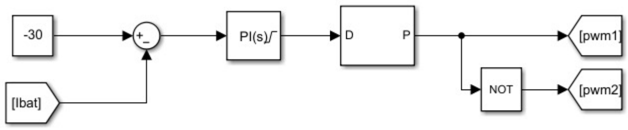

Fig. 8. DC-DC converter control scheme

comparator generator error signal. The PI controller input is connected to the comparator and the output is connected to the PWM generator. The PWM generator output generator two PWM pulses. These two pulses are controlled by bidirectional battery charger circuits. The battery charging mode PWM1 switch ON and PWM switch 2 OFF. The battery discharging modes are PWM2 ON and PWM1 OFF.

IV. SIMULATION RESULTS

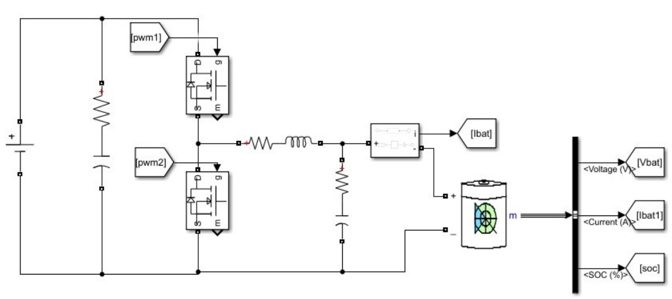

Fig. 9. Bi-directional Battery Charger

Fig.9 shows the DC-DC converter battery charger circuit designed using Simulink software. The circuit has a single DC source 800V, two MOSFET switches operated with 5kHz, bus capacitor 1000uF and the filter circuit capacitor and inductor are 20uF and 13 mH. The load side battery is nominal voltage 360V and 150AH. The PWM1 and PWM2 are switching pulses for MOSFET. The parameters Vbat, Ibat, and SOC are the battery output parameters.

TABLE I
BI-DIRECTIONAL CIRCUIT PARAMETERS

S.No	Parameter Name	Parameter Value
1	Input Voltage	800V
2	Bus capacitor	1000uF
3	Switching frequency	5Khz
4	Filter inductor	13mH
5	Filter capacitor	20uF
6	Battery nominal voltage	360V
7	Battery rated current	150A

A. Battery Charging Mode

Fig.10 shows battery charging mode with reference current 25A. The output is reached almost near 24.53 A. The presented controller is well operated in battery charging mode. In table.2 shows the battery reference voltage and battery current as well as battery nominal voltage and battery charging voltage.

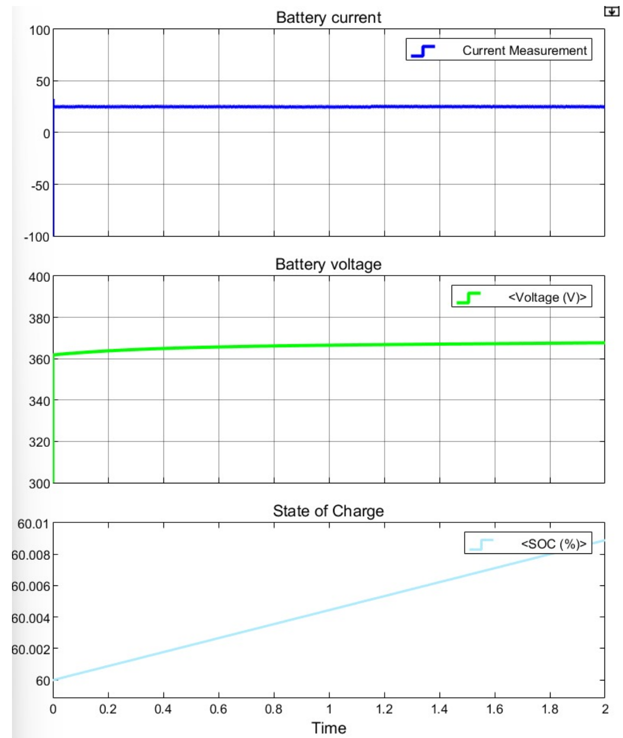

Fig. 10. Battery is in charging mode with reference current 25A

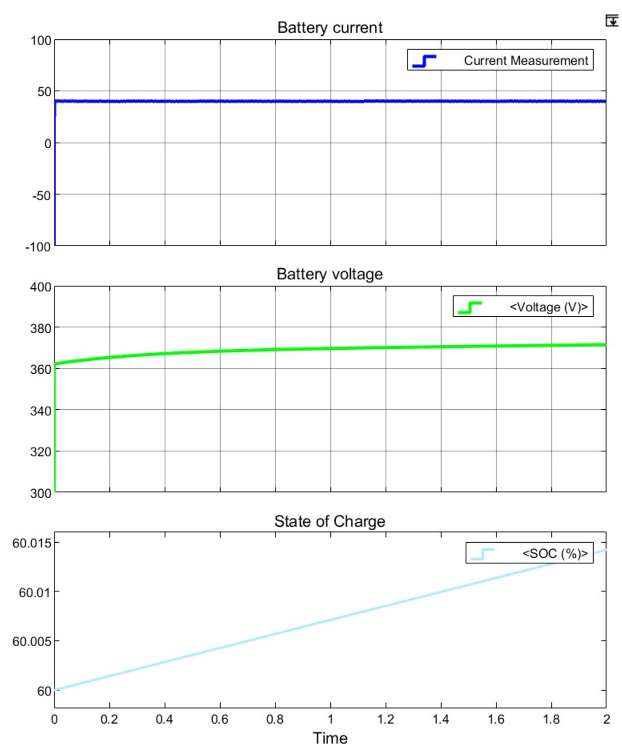

Fig. 11. Battery is in charging mode with reference current 40A

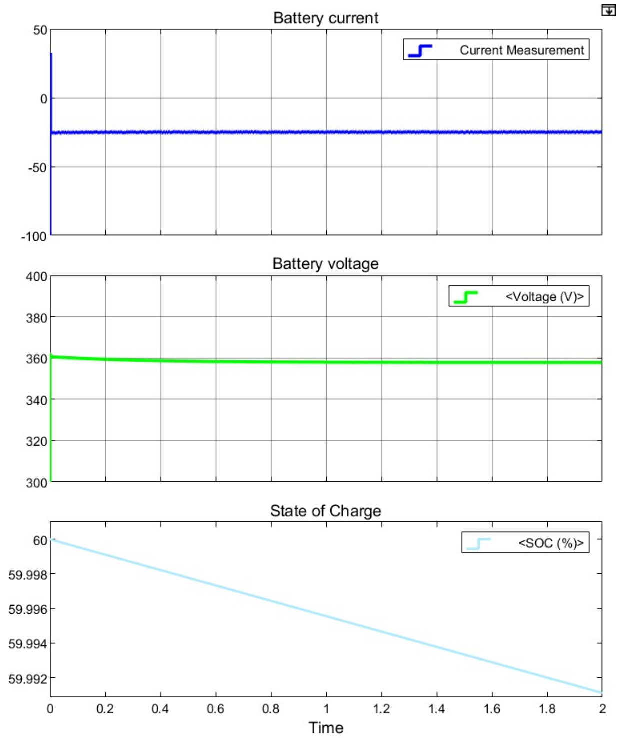

Fig. 12. Battery is in discharging mode with reference current -25A

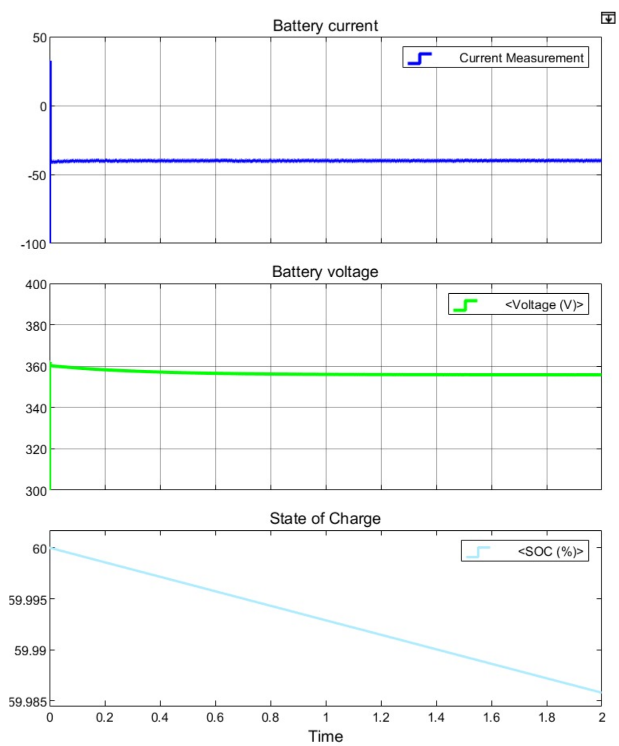

Fig. 13. Battery is in discharging mode with reference current -40A

TABLE II
BI-DIRECTIONAL CIRCUIT PARAMETERS

S.No	Reference Battery Current	Battery Current	Nominal voltage	Battery voltage
1	10A	9.497A	360V	357.9V
2	20A	19.5A	360A	358.2
3	30A	29.52A	360V	358.2V
4	40A	39.51A	360V	358.9V
5	50A	49.59A	360V	359.2V

B. Battery Discharging Mode

Fig.12 shows the battery discharging mode waveforms. This circuit is the reference current -25A and SOC 60In the battery discharging mode the circuit is operated well. During discharging mode the discharging current is proportional to the reference current.

TABLE III
BI-DIRECTIONAL CIRCUIT PARAMETERS

S.No	Reference Battery Current	Battery Current	Nominal voltage	Battery voltage
1	10A	9.497A	360V	357.9V
2	20A	19.5A	360A	358.2V
3	30A	29.52A	360V	358.2V
4	40A	39.51A	360V	358.9V
5	50A	49.59A	360V	359.2V

V. CONCLUSION

This project successfully demonstrated the design and implementation of a bi-directional battery charger circuit controlled by a PI controller. The developed DC-DC converter effectively operates in both charging and discharging modes, functioning as a buck converter during charging and a boost converter during discharging. The closed-loop PI controller was instrumental in managing the converter's performance, ensuring that the output closely tracked the desired reference values throughout the operational phases. Simulation results obtained from Simulink validated the effectiveness of the design, showcasing stable performance during both battery charging and discharging modes. Overall, this project highlights the potential of bi-directional converters in battery management systems, emphasizing their ability to maintain steady and dynamic states, which is crucial for efficient energy management in various applications. Future work could explore further optimizations in control strategies and the integration of additional features for enhanced performance.

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