

Performance Analysis of Bidirectional DC-DC Converter for Electric Vehicle Application

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Abstract

This paper describes bidirectional DC-DC converter fed separately excited dc motor for EV application. Battery fed electric vehicles (BFEVs) is required to function in three different modes namely: normal (steady-state) mode, acceleration mode and braking (regenerative) mode. During acceleration and normal modes the power flow is from battery to motor whereas during braking or regenerative mode the kinetic energy of the motor is converted into electrical energy and fed back to battery.

Keywords: Bidirectional dc-dc converter, hybrid electric vehicle, PI controller, separately excited dc motor, battery

I. INTRODUCTION

Recently bi-directional dc-dc converters are widely researched and developed for various applications. In case of the battery fed electric vehicles (BFEVs), electric energy flows between motor and battery side. For achieving zero emission, the vehicle can be powered only by batteries or other electrical energy sources. Batteries have widely been adopted in ground vehicles due to their characteristics in terms of high energy density, compact size, and reliability. The use of a Bi-directional dc-dc converter fed dc motor drive devoted to electric vehicles (EVs) application allows a suitable control of both motoring and regenerative braking operations, and it can contribute to a significant increase the drive system overall efficiency. Recently many Bi-directional dc-dc converter topologies have been reported with soft switching technique to increase the transfer efficiency.

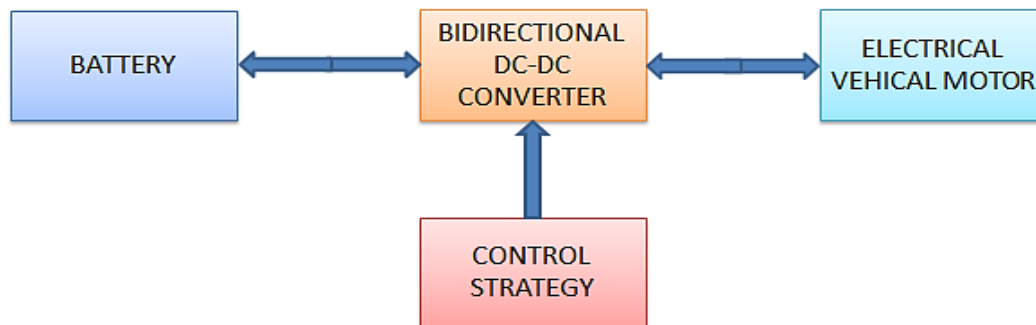


Fig. 1: Blocked diagram of proposed system

II. THE NEED FOR A BIDIRECTIONAL DC-DC CONVERTER IN THE HEV IS DUE TO THE FOLLOWING

REASONS

- 1) The system is operating at the high power and low voltage making the current to rise too high, which causes high electrical and thermal stresses in the passive as well as the active components of the system, also it increases the ohmic losses and hence decrease efficiency.
- 2) Device voltage and current stresses is even further increased up by the wide variation in the input voltage range of the system. Since device stresses depends on the output to input voltage ratio, input voltage variation further increases the components ratings to be used.
- 3) Further along with the above two factors, the parasitic ringing due to the parasitic components causes EMI emission and therefore ,the proper shielding has to be provided. All above three factors makes the converter packaging bulky, heavy and expensive. Thus there is a need for an efficient DC-DC converter to deal with this issue.
- 4) To be able to recharge the electrical energy storage system during the re-regenerative braking, and hence therefore there should be the provision of bidirectional power flow.

Some of the requirements for the Bidirectional DC-DC converters design for the HEV applications are as follows:

- High efficiency

- Lightweight & compact size
- Lower electromagnetic Interference
- Lower input and output current ripple
- Controlled power flow in spite of wide input voltage variation

III. BIDIRECTIONAL DC-DC CONVERTER WITH BATTERY AND DC MOTOR

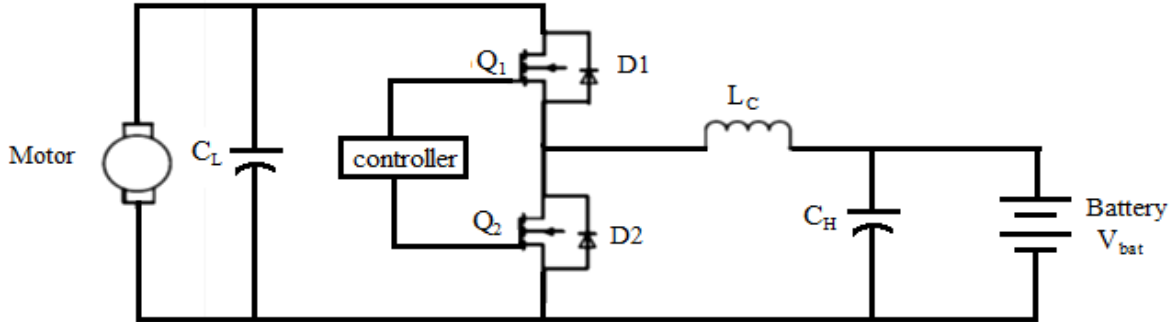


Fig. 2: Proposed Bi-directional dc-dc converter fed DC motor drive

In this topology, boost converter operation is achieved by modulating Q_2 with the anti-parallel diode D_1 serving as the boost-mode diode. With the direction of power flow reversed, the topology functions as a buck converter through the modulation of Q_1 with the anti-parallel diode D_2 serving as the buck-mode diode. It should be noted that the two modes have opposite inductor current directions. A new control model is developed using PI controller to achieve both motoring and regenerative braking of the motor. A Lithium-ion battery model has been used in this model to verify the motor performance in both motoring and regenerative mode. This controller shows satisfactory result in different driving speed commands.

A. Converter Operating Modes:

The MOSFETs Q_1 and Q_2 are switched in such a way that the converter operates in steady state with four sub intervals namely interval 1(t_0-t_1), interval 2(t_1-t_2), interval 3(t_2-t_3) and interval 4(t_3-t_4). It should be noted that the low voltage battery side voltage is taken as V_1 and high voltage load side is taken as V_2 . The gate drives of switches Q_1 and Q_2 are shown in Figure. The circuit operations in steady state for different intervals are elaborated below.

Interval 1(t_0-t_1): At time t_0 , the lower switch Q_2 is turned ON and the upper switch Q_1 is turned OFF with diode D_1 , D_2 reverse biased as shown in Figure 2(a). During this time interval the converter operates in boost mode and the inductor is charged and current through the inductor increases.

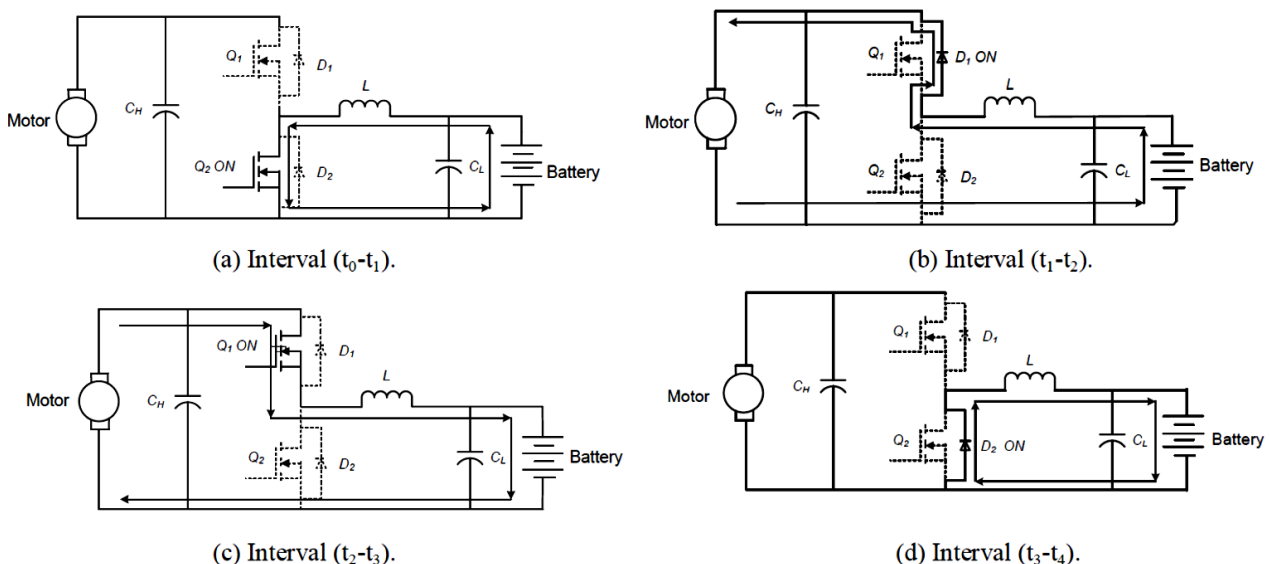


Fig. 3: Converter Operating Modes

Interval 2(t_1 - t_2): During this interval both switches Q1 and Q2 is turned OFF. The body diode D1 of upper switch Q1 starts conducting as shown in Figure 2(b). The converter output voltage is applied across the motor. As this converter operates in boost mode is capable of increasing the battery voltage to run the motor in forward direction.

Interval 3(t_2 - t_3): At time t_3 , the upper switch Q1 is turned ON and the lower switch Q2 is turned OFF with diode D1, D2 reverse biased as shown in Figure 2(c). During this time interval the converter operates in buck mode.

Interval 4(t_3 - t_4): During this interval both switches Q1 and Q2 is turned OFF. The body diode D2 of lower switch Q2 starts conducting

IV. CONTROL STRATEGY

The control circuit of the bidirectional converter is shown in Fig. to control the speed of the dc drive; one possible control option is to control the output voltage of the bidirectional converter. To control the output voltage of the bidirectional converter for driving the vehicle at desired speed and to provide fast response without oscillations to rapid speed changes a PI controller is used and it shows satisfactory result. In this control technique the motor speed ω_m is sensed and compared with a reference speed ω_{ref} .

The error signal is processed through the PI controller. The signal thus obtained is compared with a high frequency saw tooth signal equal to switching frequency to generate pulse width modulated (PWM) control signals.

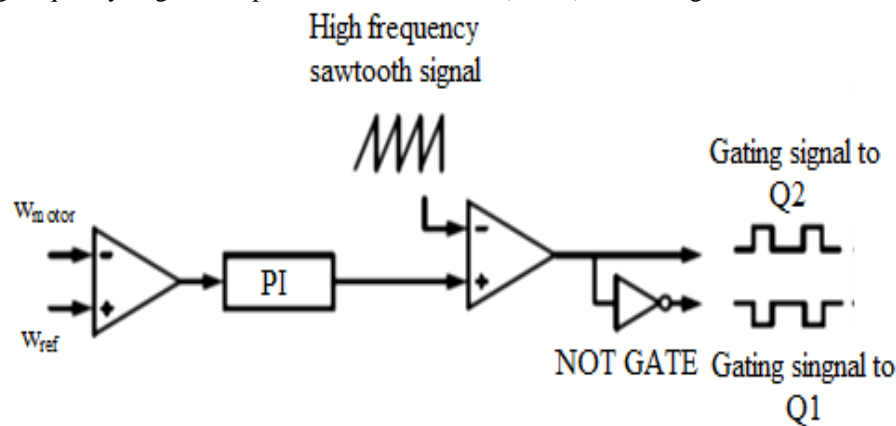


Fig. 4: Control strategy of the bidirectional dc-dc converter.

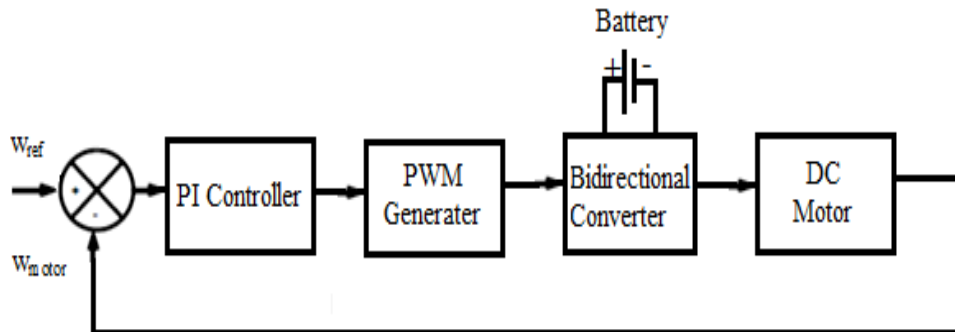


Fig. 5: Closed loop operation of the drive.

The block diagram of feedback speed control system for DC motor drive is shown in Figure; the control objective is to make the motor speed follow the reference input speed change by designing an appropriate controller. The proportional-integral(PI) controller is used to reduce or eliminate the steady state error between the measured motor speed (ω_{motor}) and the reference speed (ω_{ref}) to be tracked.

B. Parameter used in the Simulation:

The Separately excited DC motor rated at 5HP, 240V, 1750RPM
 Bidirectional converter parameters are: $L=1600 \mu\text{H}$, $C_H=470 \mu\text{F}$, $C_L=470 \mu\text{F}$, $f_{sw}=20 \text{ kHz}$
 Battery voltage = 48V, Battery capacity = 16Ah, SOC= 88%

V. SIMULATION AND RESULTS

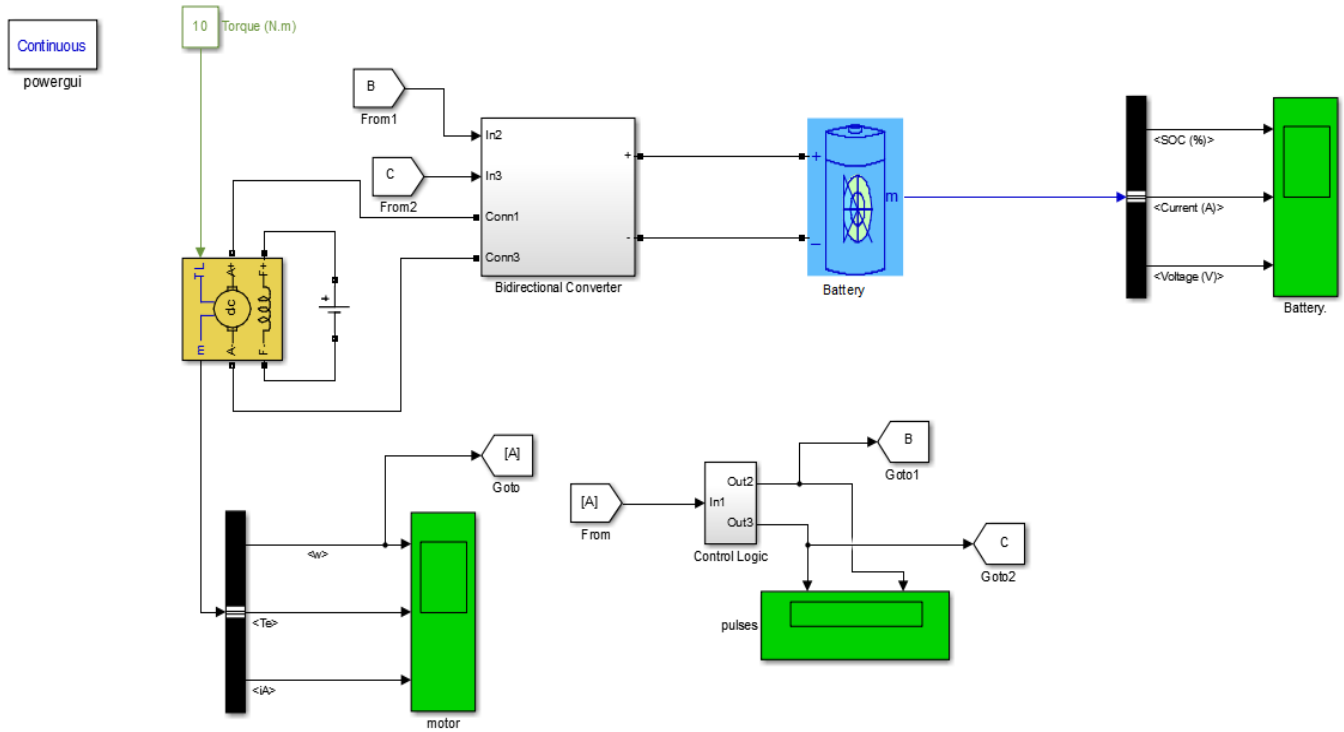


Fig. 6: Matlab simulink mode

A. For Normal condition Torque-: 10Nm, ref. speed-120rad/sec:

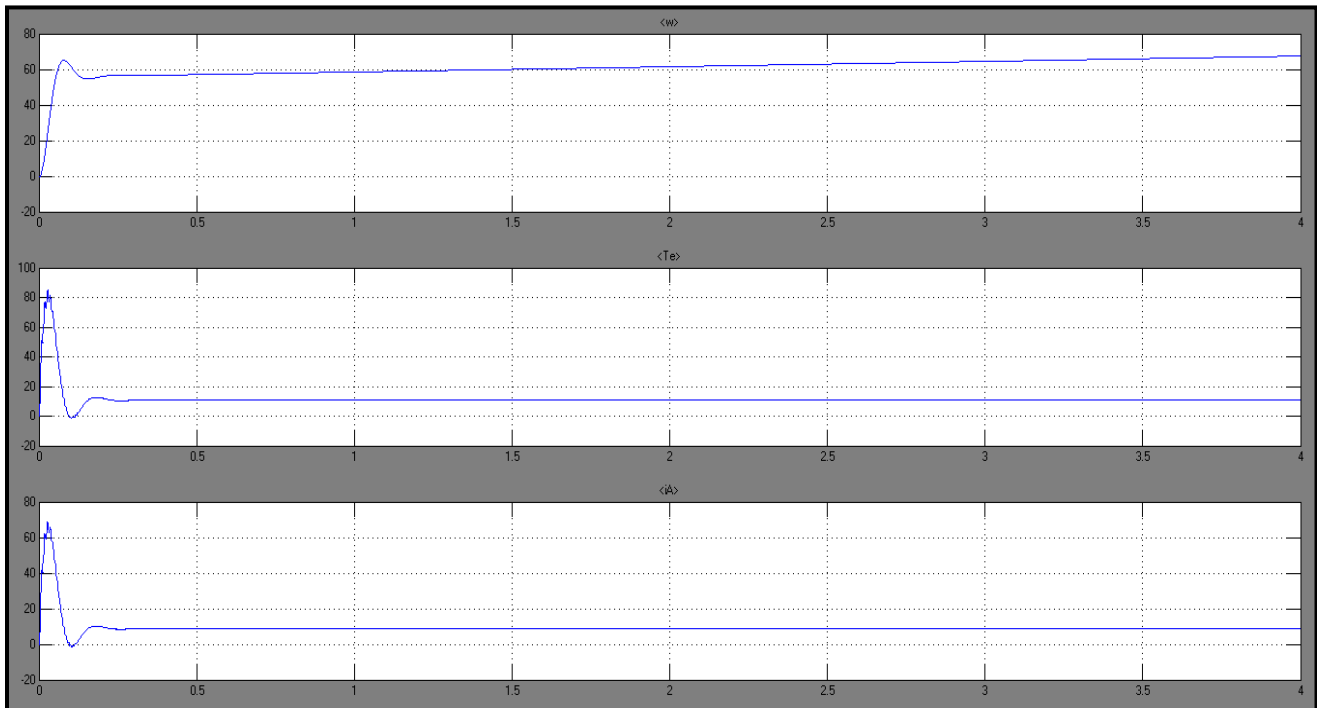


Fig. 7: Motor results

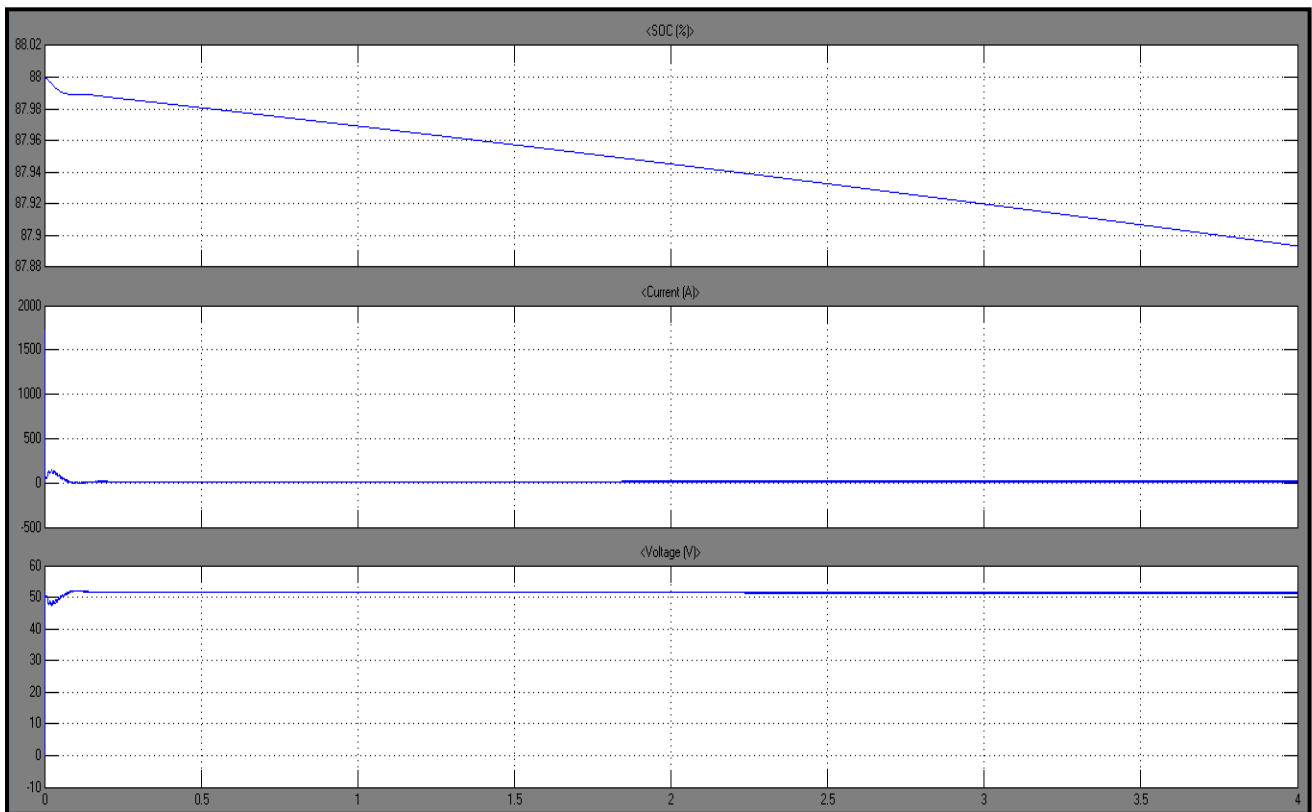


Fig. 8: Battery results

B. For Motoring Condition Torque:- 10Nm, Ref. Speed:- 60rad/Sec To 120rad/Sec:

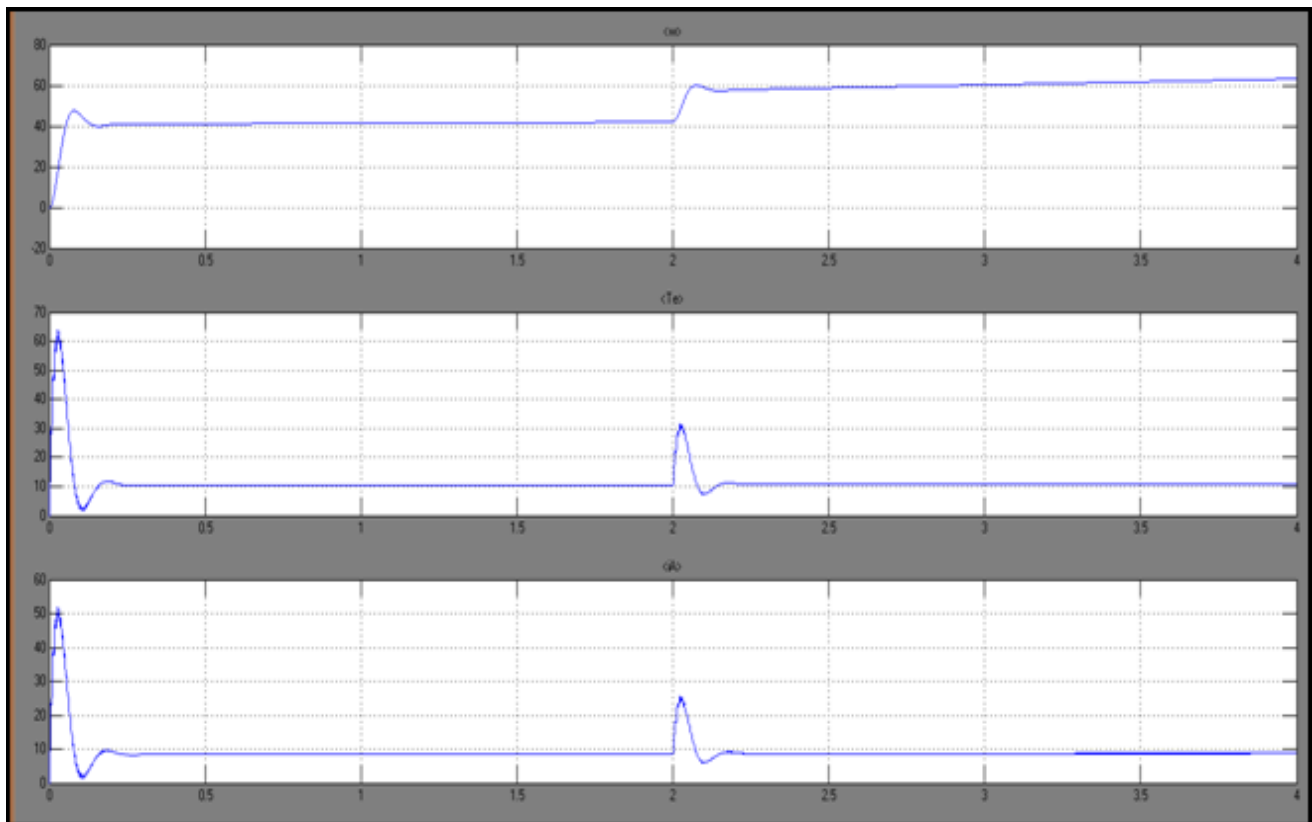


Fig. 9: Motor results

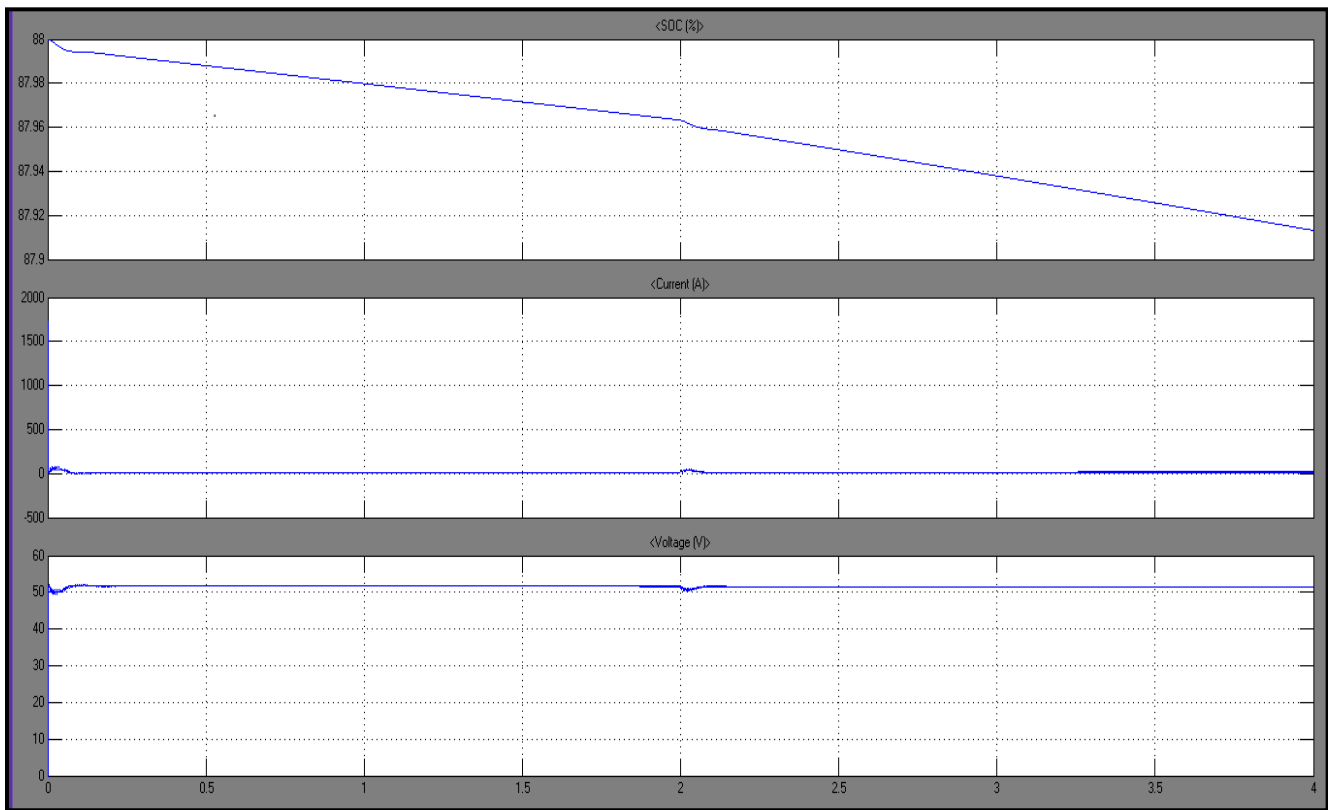


Fig. 10: Battery Results

C. For Braking Condition Torque- : 10Nm To -10Nm, Ref. Speed-: 60rad/Sec To 120rad/Sec:

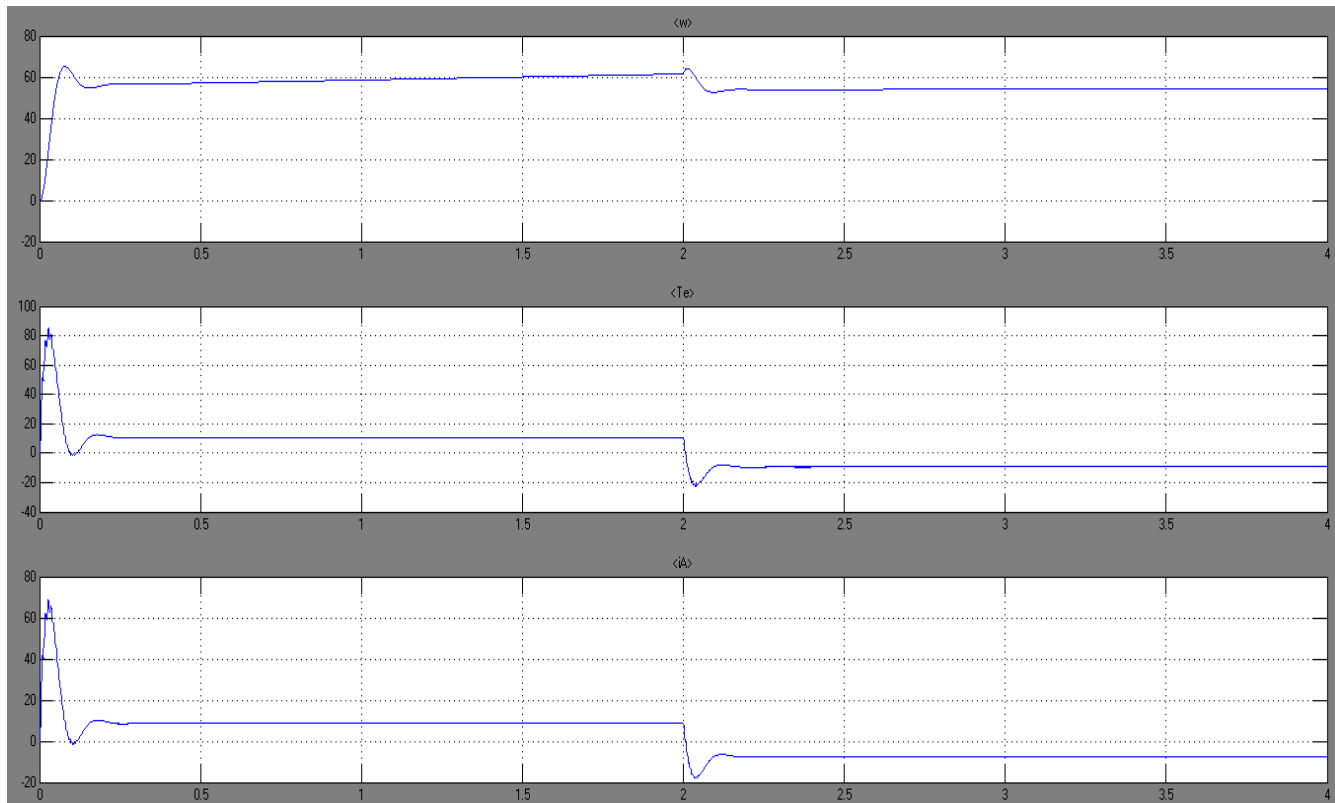


Fig. 11: Motor results

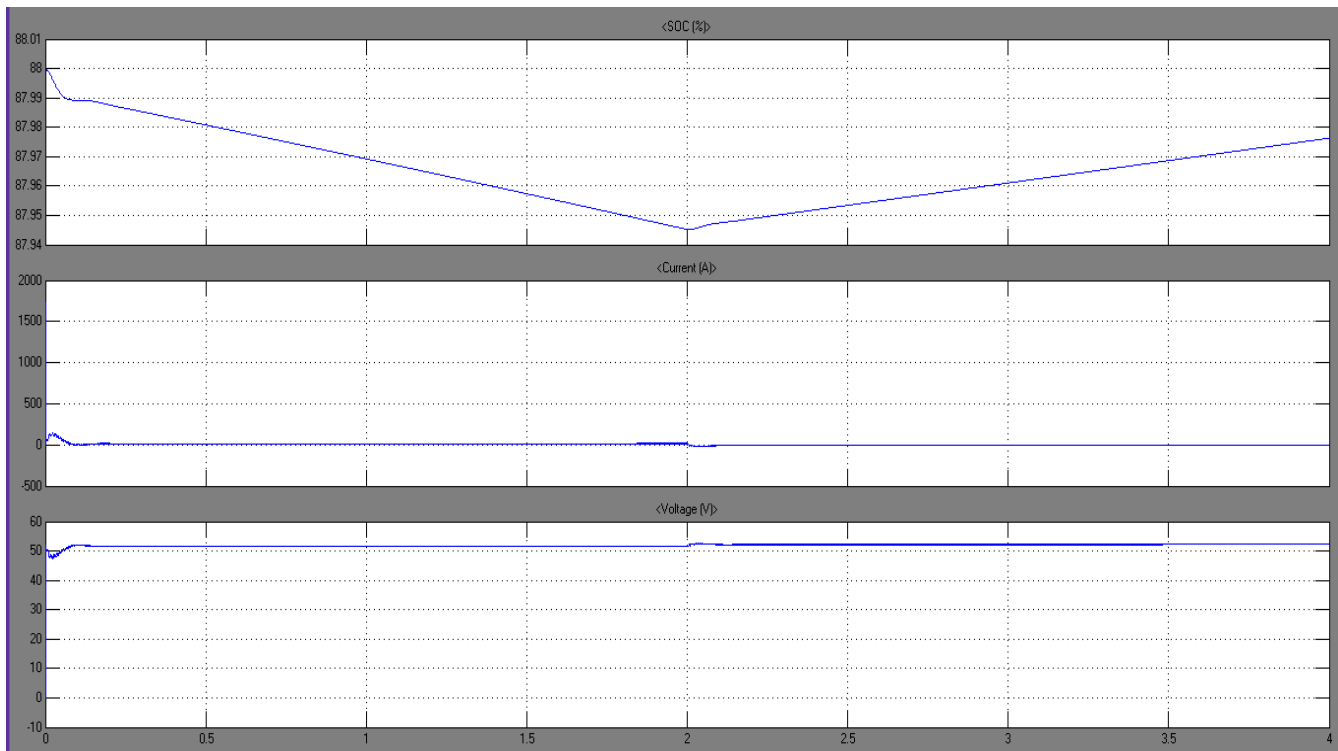


Fig. 12: Battery result

VI. CONCLUSION

I have studied a battery operated electric vehicle system and it shows satisfactory performance at different driving condition. The proposed control technique with PI controller find suitable for this electric drive. The performance of the BFEV is verified under forward motoring mode, regenerative mode and when there is step change in speed command.

The overall cost and volume of the battery operated electric vehicle is less with the least number of components used in the system.

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