ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization *Volume 5, Special Issue 5, April 2016*

International Conference on Emerging Trends in Smart Grid Technology - INCETS'16

Organized by

Dept. of EEE, College of Engineering, Trikaripur (CAPE, Government of Kerala), Cheemeni, Kasaragod, Kerala-671313, India

A Compact Multifunctional Power Electronic Interface for Plug-in Hybrid Electric Vehicles

Deepthy Andrews [1], Suchithra K.S. [2]
P.G. Student, Department of Electrical and Electronics Engineering, Vidya Academy of Science and Technology, Thrissur, Kerala, India[1]
Assistant Professor, Vidya Academy of Science and Technology, Thrissur, Kerala, India [2]

ABSTRACT : This paper proposes an innovative integrated bidirectional converter with a single-stage on-board charger to reduce the number of switches, size, and weight of the power electronic interfaces. In this structure, the charger and the bidirectional dc/dc converter share the same power stage as charging and propelling do not happen at the same time. This reduces the switching losses and hence improves efficiency. There is only minimum inductance in the circuit.

In the present work closed loop operation of bi-directional dc-dc converter feeding a dc motor and its energy recovery due to regenerative braking has been demonstrated. The effectiveness of the system is verified through the simulations using Simulink/MATLAB.

.

KEYWORDS: Electric vehicles, integrated charger, plug-in hybrid electric vehicles (PHEVs).

I.INTRODUCTION

The necessity for a better fuel economy and further reduction in greenhouse gas emissions is pushing automotive industry to go through a restructuring to electrify the vehicles and to introduce plug-in hybrid electric vehicles (PHEVs) and electric vehicles, cumulatively called plug-in electric vehicle (PEVs). A PHEV utilises rechargeable batteries or energy storage devices which can be fully charged by connecting the plug into an external electric power source.The electrical powertrain of current and upcoming PEVs is composed of an energy storage system connected to propulsion machine [1]. In addition, an add-on battery charger is inevitable part of vehicle powertrain [2]. In majority of PEVs, a bidirectional dc/dc converter is deployed between the battery and propulsion machine [3]. This converter is responsible to boost the battery voltage and efficiently control the delivered or absorbed power during acceleration or regenerative braking, respectively.

The overall electric powertrain with a single integrated power electronic converter is illustrated in Fig. 1. In this structure, the charger and the bidirectional dc/dc converter share the same power stage as charging and propelling do not happen at the same time. As a result, overall cost, weight, and volume of the power electronic converter can be reduced effectively through reducing the number of switches, sensors, and large volume energy storage elements such as inductors. In this regard, this paper pro-poses a new integrated single-stage charger topology for PEVs, which can also be used in retrofit conversion of an HEV to a PHEV. The proposed converter uses minimum circuit components offering a further cost-effective solution in comparison to the other integrated charger topologies presented in the literature [4]–[6]. With the boost charging capability, it enables operating with wide single-phase charging voltage ranges in-cluding 120/220/240 V_{AC} ,. . In addition, it is capable of stepping up and stepping down the voltage in both power flow directions during cruising and acceleration, as well as regenerative braking.

This paper is organized as follows: In Section II, the proposed integrated topology is introduced and operation modes are explained in detail. The overall control scheme developed for controlling each essential operation mode is explained in Section III. Section IV describes the simulation results.Finally, conclusions drawn from the study are presented in Section V.

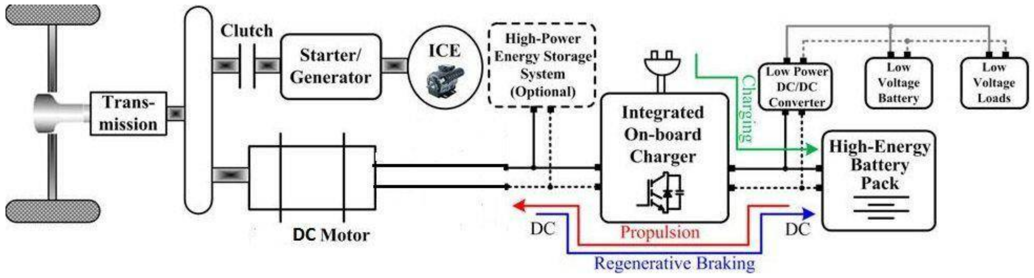


Fig:1. System level structure of a parallel powertrain PHEV with on-board integrated battery charger.

II.PROPOSED INTEGRATED TOPOLOGY AND OPERATION MODES

The proposed integrated interface is shown in Fig. 2. Basically, the circuit consists of four active switches with body diodes, one inductor and one diode bridge.

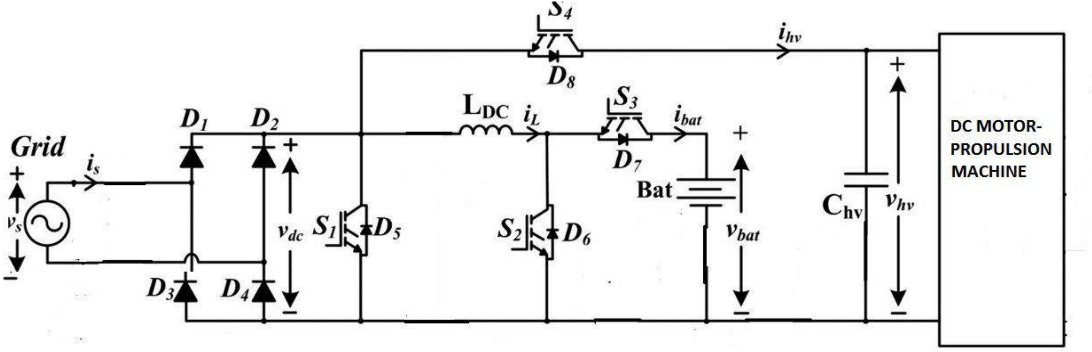


Fig. 2. Proposed integrated topology.

The proposed integrated topology has basically three modes of operation namely charging, propulsion, and regenerative braking. During propulsion and regenerative braking operations, both stepping-up and stepping-down capabilities are possible, allowing more flexible control, capability of efficiently capturing regenerative braking energy, as well as flexibility of choosing wide ranges for battery nominal voltage. The states of the switches in each mode are summarized in Table I, where PWM⁻ represents the complementary signal of PWM.

Table I
Operation modes and switching sequence of the proposed converter

Operation Mode	Mode	S_1	S_2	S_3	S_4	D_5	D_6	D_7	D_8
Propulsion	Boost	PWM	OFF	ON	OFF	-	-	-	PWM
	Buck	OFF	OFF	PWM	OFF	-	PWM	-	ON
Regeneration	Boost	OFF	PWM	OFF	ON	-	-	PWM	-
	Buck	OFF	OFF	OFF	PWM	PWM	-	ON	-
Charging	Boost	OFF	PWM	OFF	OFF	-	-	PWM	-

A. Mode 1: Boost Mode During Propulsion

In this mode, integrated converter will boost the battery voltage to the dc bus voltage. The conduction paths according to the state of the boost switch S_1 are shown in Fig. 3(a). In this operation, S_1 is used as the main boost switch and S_3 is turned ON When S_1 is turned ON, the inductor stores energy and mean-while capacitor supplies energy to motor.

When S_1 is turned OFF, inductor transfers the stored energy to motor by generating a voltage high enough to force D_8 to conduct and charges the high voltage bus capacitor C_{hv}.

B. Mode 2: Buck Mode During Propulsion

In buck mode [see Fig. 3(b)], only S_3 is pulse width modulated and the other switches are always in OFF state. When S_3 is turned ON, the input voltage source supplies energy to the inductor and to the load whereas, when S_3 is turned OFF, D_6 is forward biased and energy is transferred to the load. During propulsion, the energy flow is from battery in both buck and boost modes.

C. Mode 3: Boost Mode During Regenerative Braking

Boosting capability during regenerative braking operation provides additional advantage, through capability of capturing the power during low speeds. In fact, in urban traffic, where ve-hicles are driven in low speeds, the generated voltage across the terminals of the propulsion machine is lower and if the interface converter does not have boosting capability during regenerative braking, this energy will be lost. With boosting capability in reverse direction (from machine to battery), this energy can be recovered.

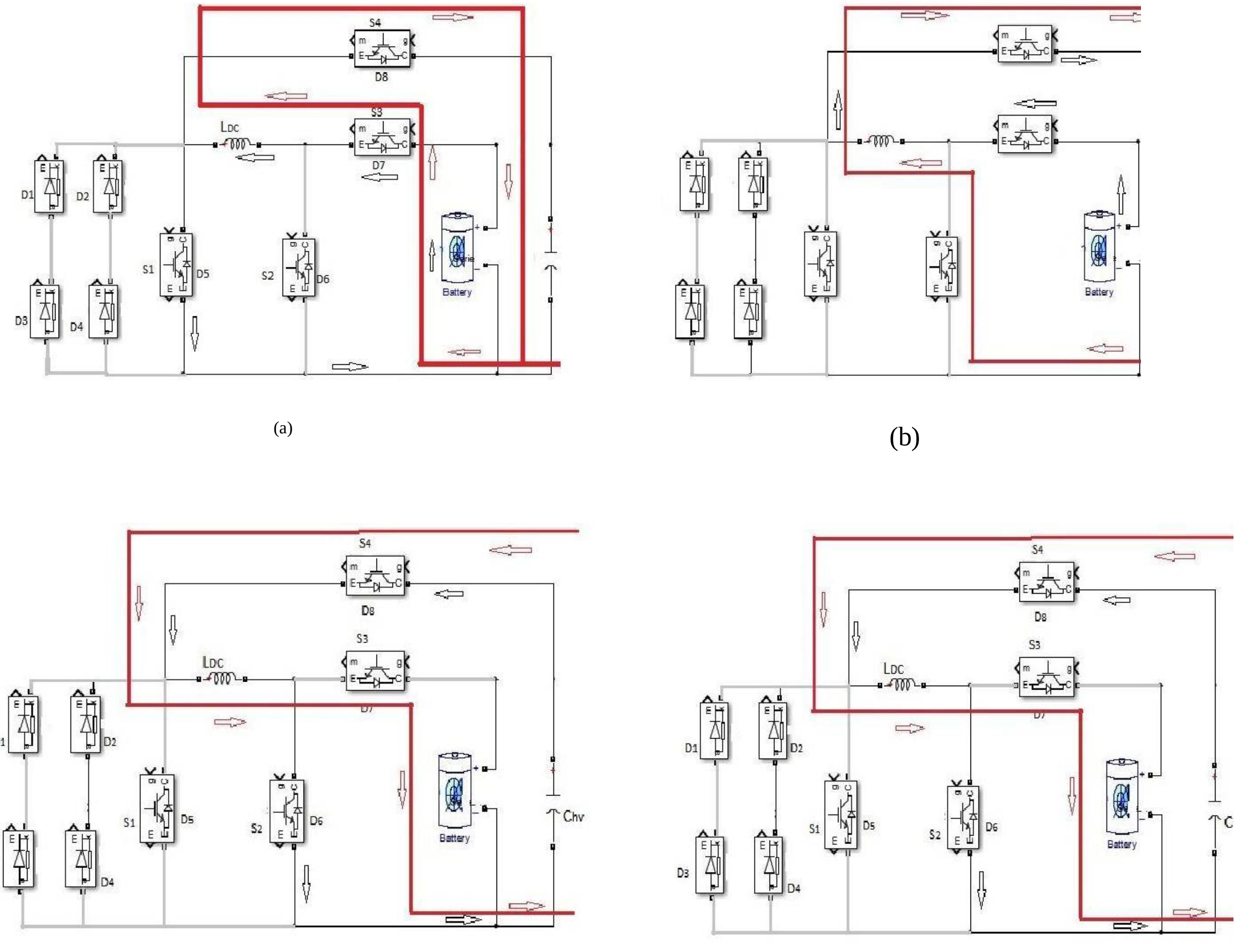
The buck and boost operating modes during regenerative braking are similar to the ones during propulsion but in reverse direction. The conduction intervals are shown in Fig. 3(c). In this mode, S_4 is always ON, and S_2 is pulse width modulated and the rest of switches are in OFF state.

D. Mode 4: Buck Mode During Regenerative Braking

The buck operation is an essential mode as the highest braking energy emerges at high speeds inducing high voltage across the propulsion machine terminals. The operation of the circuit in this mode is shown in Fig. 3(d). The high voltage at the dc bus is stepped down by switching S_4 . In the conduction period of S_4 , inductor stores energy with a terminal voltage of $V_i - V_o$ and energy is transferred from high voltage dc bus to battery through D_7 . During freewheeling operation, inductor transfers its energy to battery, where capacitor discharges over the battery as well.

E. Mode 5: Charging Operation

The integrated on-board charger operates as an ac/dc boost rectifier. The operation of the circuit in charging mode is shown in Fig. 4. When S_2 is ON, the inductor is short circuited and stores a certain amount of energy based on applied input voltage. Meanwhile, the capacitor connected in parallel to battery supplies energy to the load. Only diodes D_1 and D_4 are conducting in this mode. Diodes D_2 and D_3 will conduct depending on the grid voltage polarity. During the time when S_2 is turned OFF, D_7 is forced to conduct and the inductor current decreases under the influence of $V_{\text{grid}} - V_{\text{bat}}$. At the same time, the capacitor in parallel with battery is charged as well.



(a)

(b)

(c)

(d)

Fig.3.Operation modes of the converter: (a) boost operation during propulsion, (b) buck operation during propulsion (c) boost operation during regenerative braking, (d) buck operation during regenerative braking.

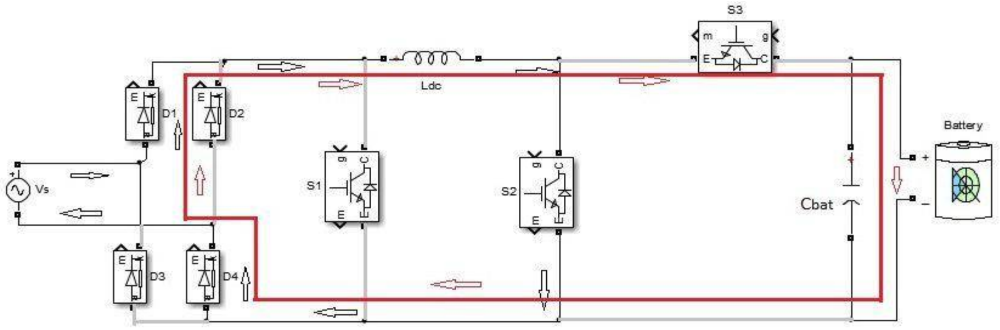


Fig. 4. Current flow during charging.

III.CONTROL STRATEGY

The control circuit of the proposed integrated topology is shown in fig 5.To control the speed of the dc drive ,one possible control 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.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 sawtooth signal equal to switching frequency to generate pulse width modulated (PWM) control signals.

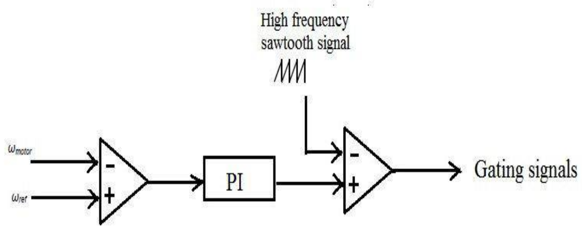


Fig 5.Control of bidirectional dc-dc converter

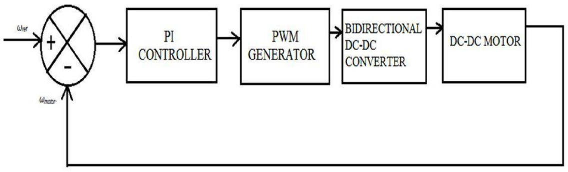


Fig 6.Closed loop operation of the drive

The block diagram of feedback control system for DC motor drive is shown in fig 6;the control objective is to make the motor speed follow the reference input speed change by designing an approporiate 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.

IV.SIMULATION RESULTS

A separately excited DC motor is used as load to the bidirectional dc-dc converter .The motor rated at 15kW,240 V,1750rpm.The simulations are carried out using MATLAB /SIMULINK . For the test condition of the proposed drive topology the following values of the different components of the converter are considered.

Table II: Simulation Parameters

Components	***Parameters***
Inductor	50 mH
Capacitor	750µH
Switching Frequency	20kHz
Battery voltage	250V
Battery Capacity	100Ah

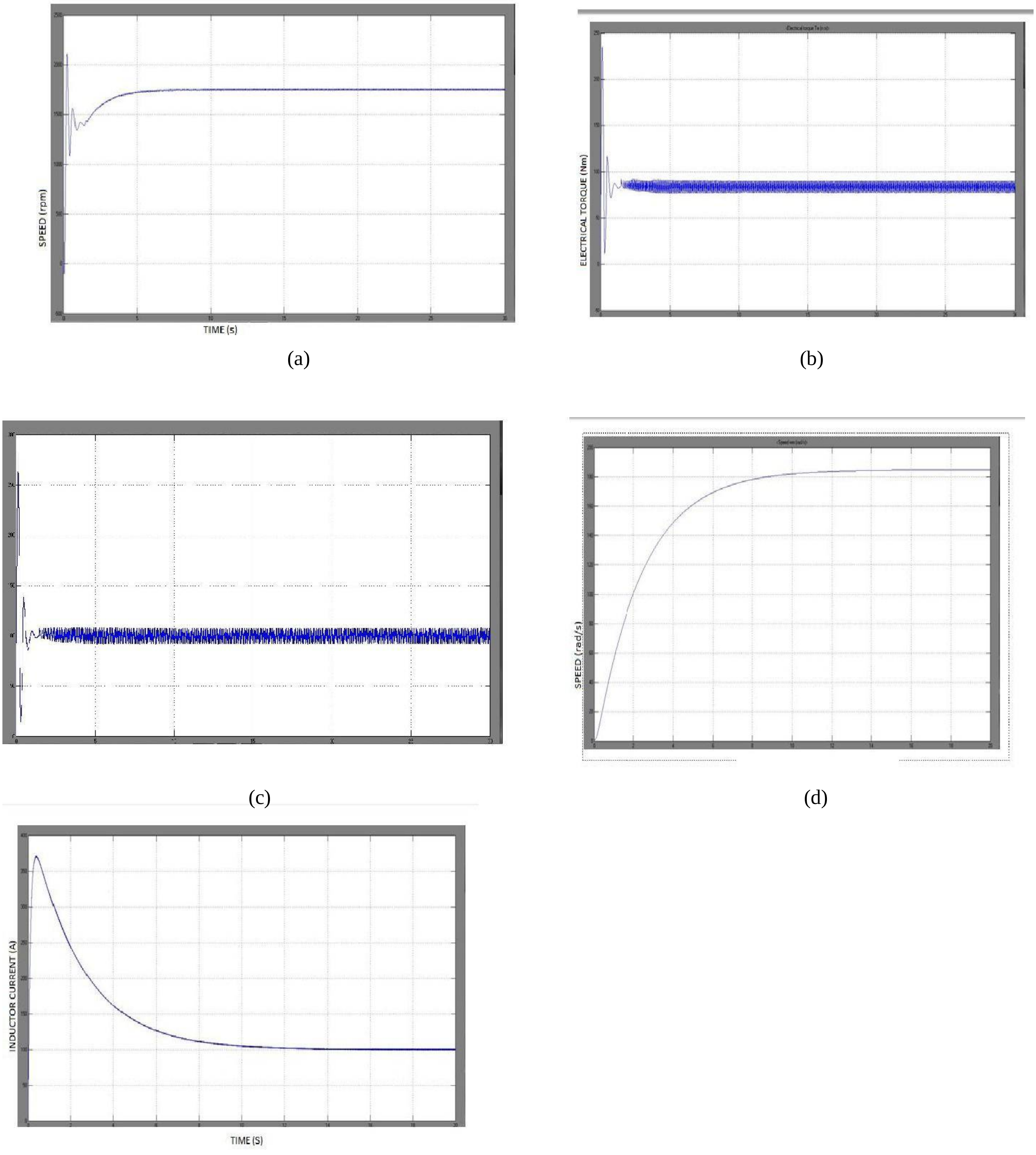
A total of two cases of the drive system during propulsion buck mode are studied:1)with step signal as reference and 2) with ramp as reference , a ramp signal which gets settled at a speed of 1700 rpm is given as reference indicating the gradual change of speed during acceleration. The simulation is carried out for a) motor speed, b) torque, c) inductor current, d) battery current, e) state of charge, f) battery voltage.

Case 1:With step as reference

Figure 6(a) shows the simulation result of the drive system at a reference speed of 1750rpm for a total simulation time of 20 sec. Motor speed reaches its steady state speed at time less than 0.5 sec.

Case 2: With ramp as reference

Figure 6 (d) shows the simulation result of the drive system at a reference speed of 1750rpm for a total simulation time of 20 sec.Motor speed reaches its steady state at 10 sec.



(a) (b)

(c) (d)

(e)

Fig.6 Simulation results: (a) Speed tracking of motor during propulsion buck mode with step reference , (b) Torque of motor during propulsion buck mode with step reference (c)Inductor current of converter during propulsion buck mode with step reference, (d) & (e),Speed &,inductor current of propulsion buck mode during ramp as reference.

Simulations are also performed for the regenerative braking mode when the speed is changed from 1750rpm to 100rpm, where the speed is decreasing and torque has reverse characteristic as shown in Figure 7(a),(b).Figure 8 (a),(b),(c) shows the battery current, state of charge and battery voltage.

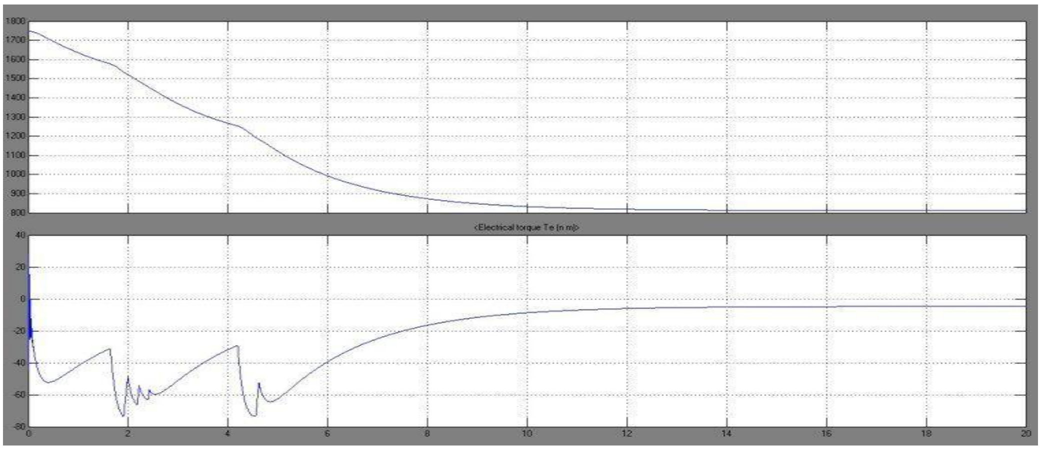
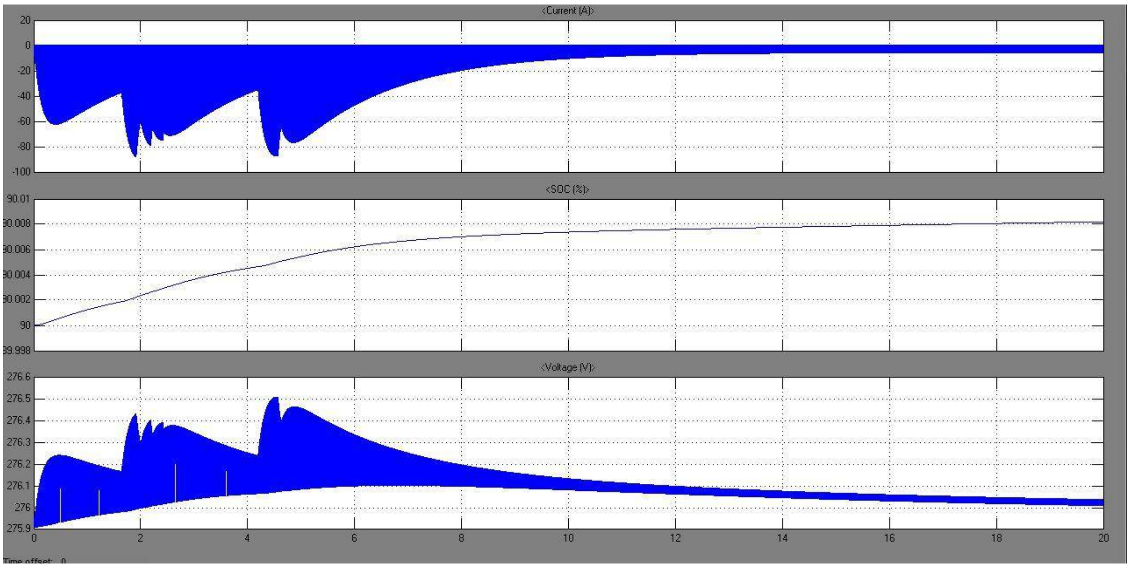


Fig 7(a): Regeneration boost mode speed (b) torque of motor



8(a) Battery current, (b)SOC (c)Voltage

V.CONCLUSION

This work demonstrates the performance of a PHEV with integrated topology and it shows satisfactory performance at different driving condition. The proposed control technique with PI controller find suitable for electric drive. The performance of the PHEV is verified under propulsion buck mode and regenerative boost mode and when there is change in speed command. The overall cost and volume is less with least number of components and due to the elimination of additional circuitry used in the system.

REFERENCES

[1] A. Emadi, Y. J. Lee, and K. Rajashekara, "Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles," *IEEE Trans. Ind. Electron.*, vol. 55, no. 6, pp. 2237–2245, Jun. 2008.

[2] F. Musavi, M. Edington, W. Eberle, and W. G. Dunford, "Evaluation and efficiency comparison of front end AC-DC plug-in hybrid charger topologies," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 413–421, Mar. 2012.

[3] Q. Wei, C. Honnyong, P. Z. Fang, and L. M. Tolbert, “55-kW variable 3X DC-DC converter for plug-in hybrid electric vehicles,” *IEEE Trans. Power Electron.*, vol. 27, no. 4, pp. 1668–1678, Apr. 2012.

[4] Y. J. Lee, A. Khaligh, and A. Emadi, “Advanced integrated bidirectional AC/DC and DC/DC converter for plug-in hybrid electric vehicles,” *IEEE Trans. Veh. Technol.*, vol. 58, no. 8, pp. 3970–3980, Oct. 2009.

[5] H. Chen, X. Wang, and A. Khaligh, “A single stage integrated bidirectional AC/DC and DC/DC converter for plug-in hybrid electric vehicles,” in *Proc. IEEE Veh. Power and Propulsion Conf.*, Sep. 2011, pp. 1–6.

[6] S. Dusmez and A. Khaligh, “A novel low cost integrated on-board charger topology for electric vehicles and plug-in hybrid electric vehicles,” in *Proc. App. Power Electron. Conf.*, Feb. 2012, pp. 2411–2616.