DESIGN AND IMPLEMENTATION OF AN ULTRA CAPACITOR BASED MOTION CONTROL IN ELECTRIC/HYBRID ELECTRIC VEHICLE

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Abstract: **Energy storage systems (ESS) have become one of the vital areas of research in Electric/Hybrid Electric vehicles. The battery energy storage systems are not economical both in terms of weight and cost in order to meet high peak power demands owing to their less power densities. In order to overcome the short comings of battery energy storage systems, a novel Battery/Ultra-Capacitor based Hybrid Energy Management System (HEMS) with motion control for Electric/Hybrid Electric vehicles has been proposed in this paper to meet the extra energy storage requirements in order to handle the surge currents. The proposed configuration consists of a battery in conjunction with an ultra-capacitor and a DC-DC converter to uphold the voltage of ultra-capacitor. The results are simulated using MATLAB /SIMULINK software and validated with experimental setup.**

***Keywords*—** Hybrid Electric Vehicle, Ultra-capacitor, Energy Management system, Motion control.

1. INTRODUCTION

Energy storage system (ESS) is the heart of electric vehicles. Battery is one of the commonly used energy management option in electric vehicles. The challenge concerning the battery energy storage systems is that they are not economical both in terms of weight and cost in order to meet high peak power demands owing to their less power densities also thermal management is a burning issue for high power density batteries [1]. Owing to the swift variation in the load profile due to the road traffic circumstances, the energy management system undergoes various charging (deceleration mode/regenerative braking) and discharging (acceleration mode) cycles and this affects the health of the battery [2]. Balancing the individual cells in an energy management system is a complicated issue which needs to be addressed as it affects the life of the battery due to recurrent charging and discharging cycles [3]. The Hybrid Energy Management System (HEMS) has been proposed as an alternative to overcome the above mentioned challenges of storage systems. The idea behind HEMS is to use an ultra-capacitor in conjunction with the battery to attain a superior performance. The architecture of an Ultra-capacitor/battery based hybrid vehicle is shown in figure.1.

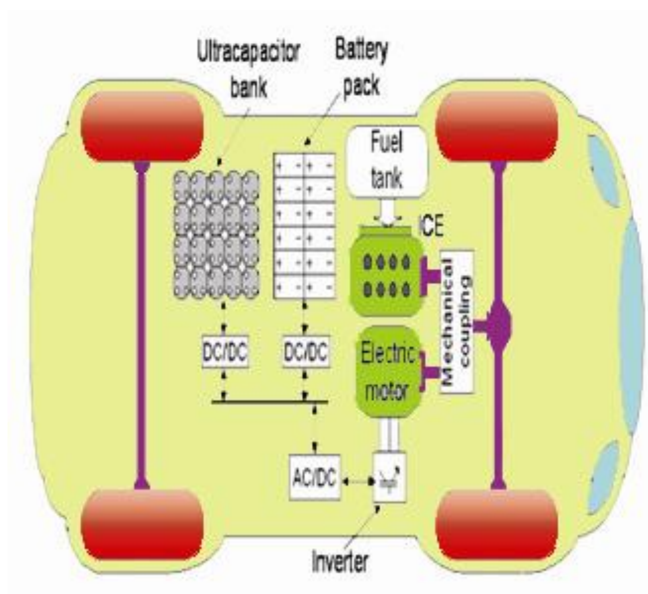

Figure.1 Hybrid Electric vehicle with ultra capacitor and Battery system

2. ULTRA CAPACITOR BASED MOTION CONTROL OF EV/HEV

The conventional design of the HEMS is shown in Figure.2. In this configuration the voltage of the DC link is maintained constant as the battery pack is connected directly to it [5]. The problem with this design is that the energy can never be absorbed by the ultra-capacitor during regenerative breaking. Also the bi-directional DC-DC converter employed in this design cannot be able to handle the power of the ultra-capacitor owing to its smaller size.

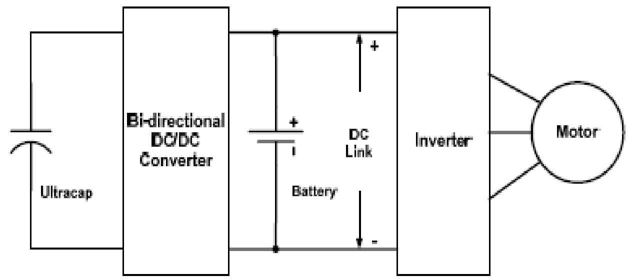

Figure.2. Ultra-capacitor/Battery Configuration

The conventional design of the HEMS is slightly modified by swapping the positions of battery and ultra-capacitor as shown in Figure.3 is employed to make the ultra-capacitor work as a low pass filter in a wider range with the aid of the control strategy applied to this configuration.

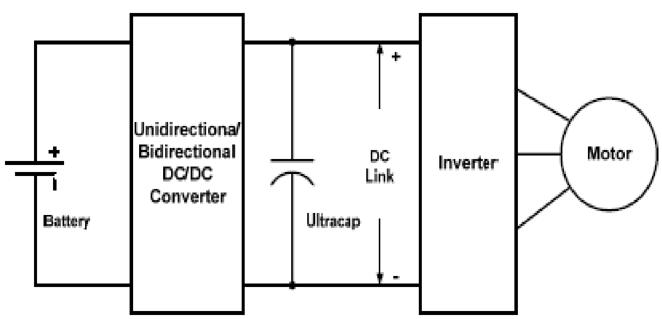

Figure.3. Battery/Ultra-capacitor Configuration

To make even better use of the ultra-capacitor, a cascaded configuration of two bi-directional DC-DC converters is implemented by incorporating one more bi-directional DC-DC converter in between the DC link and ultra-capacitor as shown in Figure.4 to extract more working range.

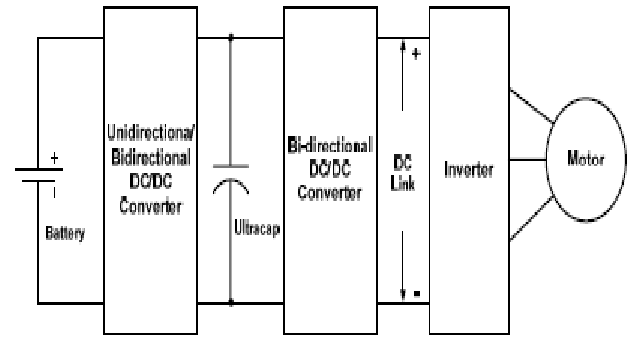

Figure.4. Cascaded Configuration

The proposed topology of HEMS is shown in Figure.5. In this configuation both ultra-capacitor and battery banks are connected to DC link in such a way that ultra-capacitor which is of higher voltage rating is connected directly to it to meet the peak power demands while the battery which is of lower voltage rating is connected to it through a power diode. To transfer the energy between the battery and ultr-capacitor a bi-directional DC-DC converter is incorporated between them. The voltage of the battery in most of the cases is usually maintained lesser than that of the ultra-capacitor, thereby the diode is usually reverse biased.

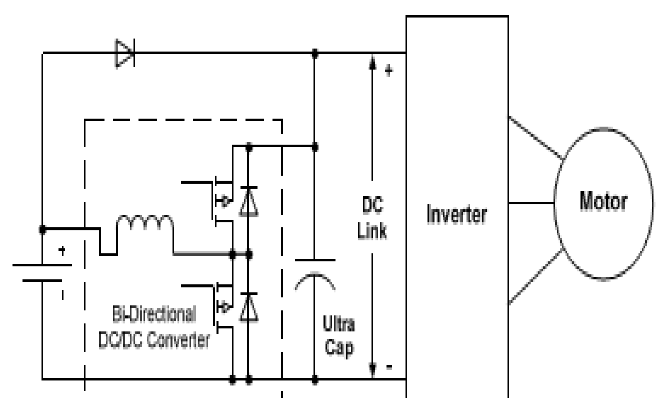

Figure.5 Proposed HESS

The cruising operation of the electric/hybrid electric vehicle with the proposed HEMS is as follows:

A. Low Power Mode

When the power requirement is equal to or falls behind the power transfer capability of a bi-directional DC-DC converter, the mode of operation is termed as low power mode as shown in the Figure.6. In this mode ultra-capacitor can alone supply the energy to the dc link.

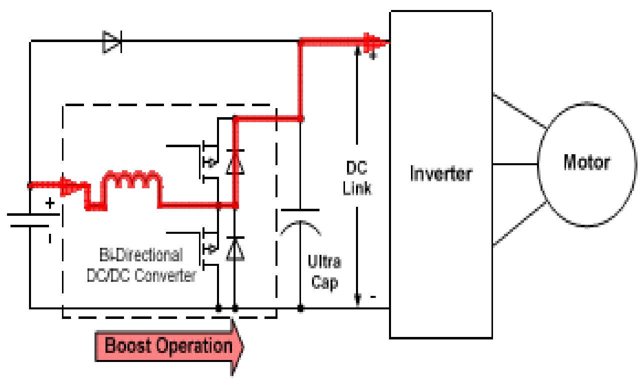

Figure.6 Low power Mode

B. High Power Mode

When the power requirement is more than the power transfer capability of a bi-directional DC-DC converter, the mode of operation is termed as high power mode as shown in the Figure.7. In this mode ultra-capacitor alone cannot provide the required energy to the dc link. Therefore the bi-directional DC-DC converter is controlled such that the energy requirement can be fed by ultra-capacitor in conjunction with battery via power diode as well.

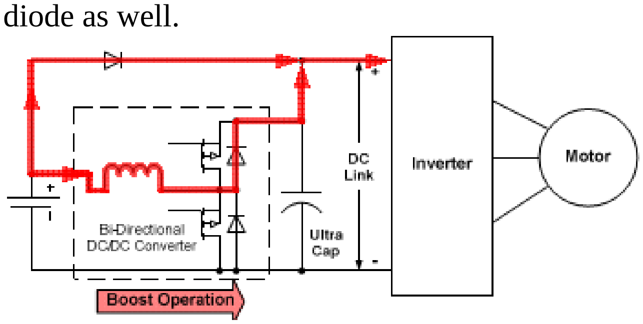

Figure.7 High Power Mode

C. Regenerative Mode

In regenerative mode, there are two possible modes of operation through which energy flow can takes place. The energy traversing path in the first mode is shown in Figure.8. In this mode of operation, the energy obtained from regenerative braking will be injected directly into the ultra-capacitor.

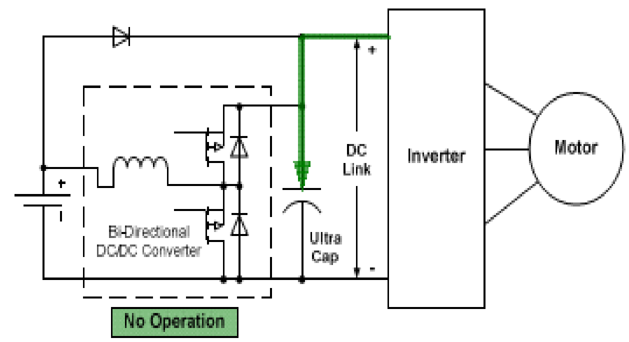

Figure.8 Regenerative braking in Phase-1 energy flow

The energy traversing path in the second mode is shown in Figure.9. In this mode of operation, the energy obtained from regenerative braking will be utilized for charging the battery controllably via bi-directional DC-DC converter which has been controlled to work in buck mode. This controlled charging improves the health of the battery.

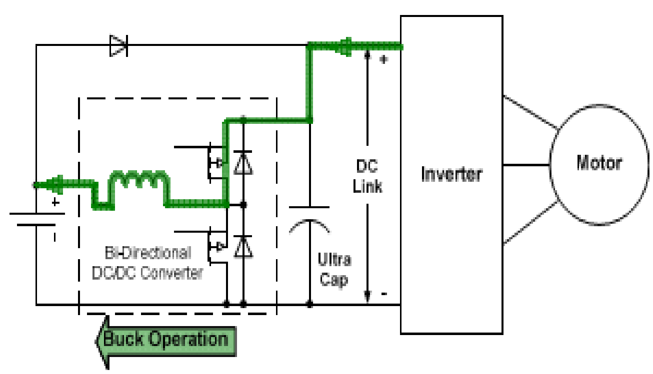

Figure.9. Regenerative braking in Phase-2 energy flow

D. Acceleration Mode

In acceleration mode as shown in figure.10, initially ultra-capacitor alone supplies the energy to the DC link as the power requirement is equal to or less than the power transfer capability of the bi-directional DC-DC converter i.e., low power mode of operation. When load demands more power ultra-capacitor alone cannot provide the required energy to the dc link and therefore the bi-directional DC-DC converter is controlled such that the power requirement can be fed by ultra-capacitor in conjunction with battery as well i.e., high power mode of operation[10-12].

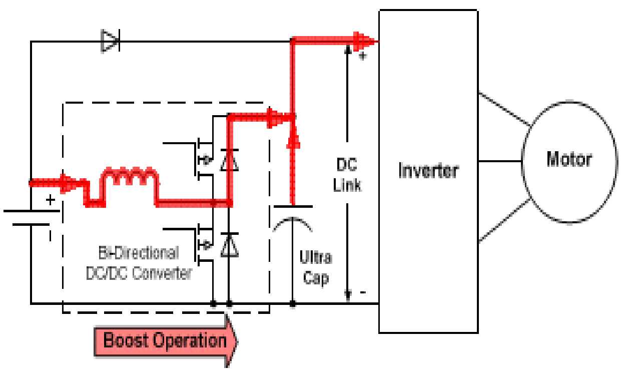

Figure.10.Acceleration Mode

3. SOFTWARE REALIZATION OF THE PROPOSED TOPOLOGY

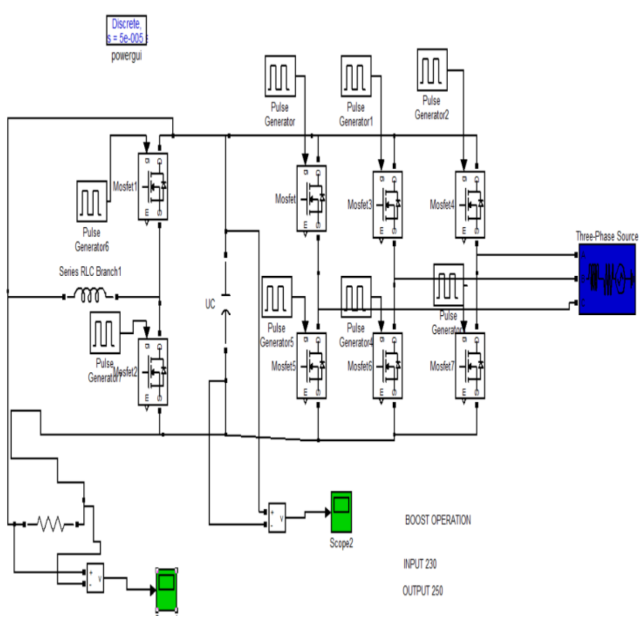

Figure.11.Simulation model of Boost /Buck converter

Figure.11 shows the simulation diagram of Boost/Buck Converter. In a boost converter output voltage is greater than input voltage [8-9]. The conversion ratio of Boost converter is given by

$$\frac{V_0}{V_{in}} = \frac{I_{in}}{I_0} = \frac{1}{1-D} \quad (1)$$

Where, D is the Duty cycle of the converter.

$$V_{in} = V_0(1-D) \quad (2)$$

$$I_{in} = \frac{I_0}{1-D} \quad (3)$$

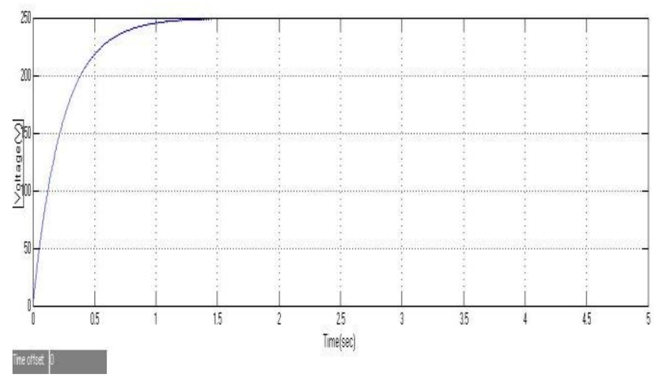

Figure.12.Simulation Result of Boost Converter

Figure.12 and Figure.13 shows the simulation result of Boost and Buck Converter [13]. In Buck converter output voltage is smaller than input voltage and output current is greater than input current. The conversion ratio is given by

$$\frac{V_0}{V_{in}} = \frac{I_{in}}{I_0} = D \quad (4)$$

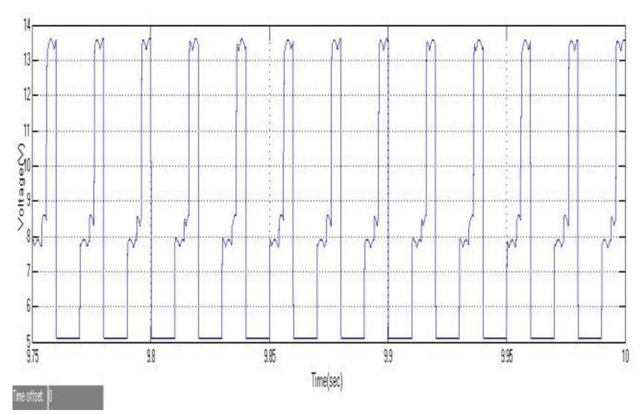

Figure.13.Simulation Result of Buck Converter

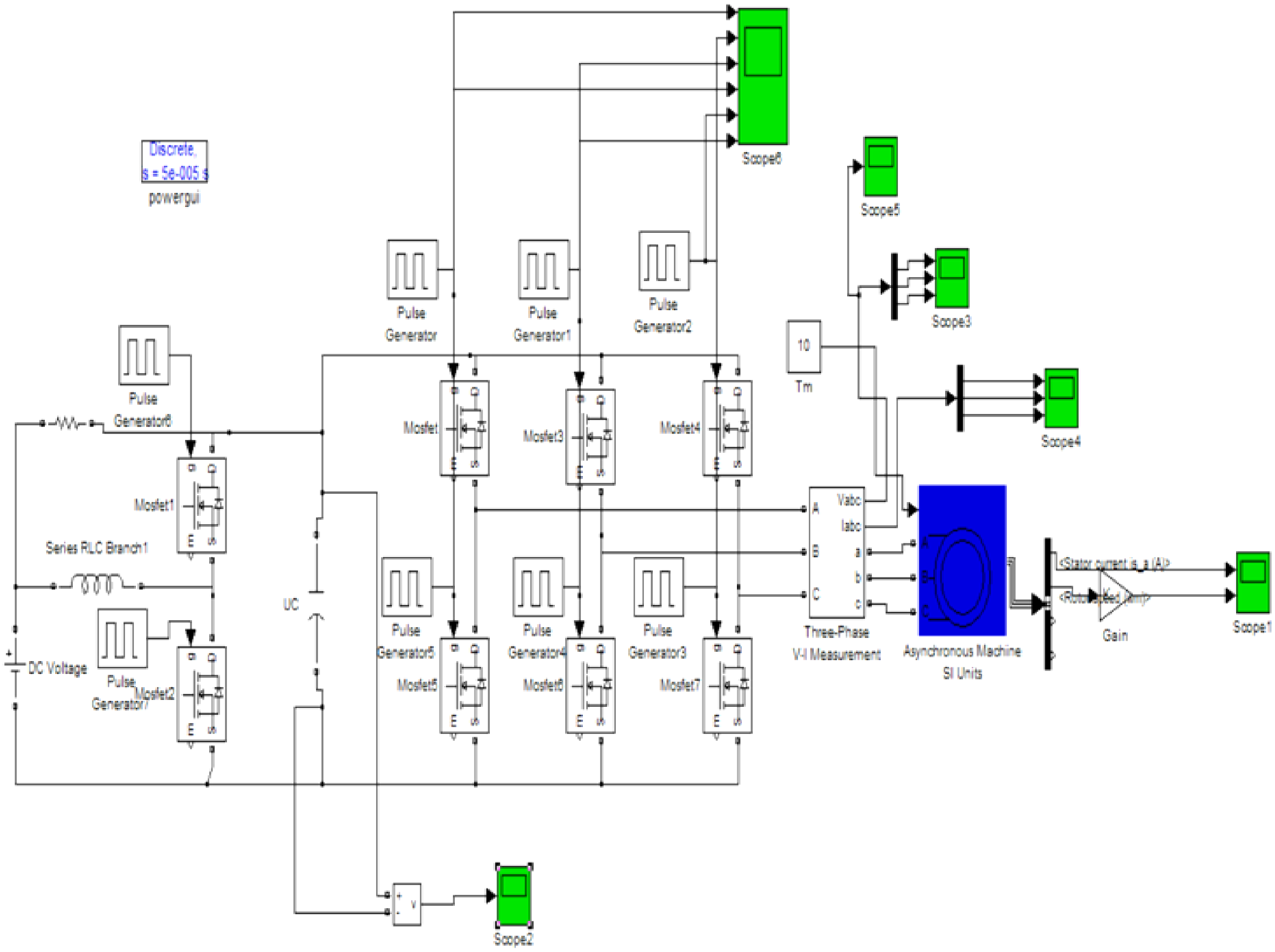

Figure.14.Simulation Model of Proposed HESS system

Table.1.Ratings of Proposed system

COMPONENT	**RATING**
DC voltage	100 V
Resistance	0.0001Ω
Inductor	10mH
Ultra capacitor	16.67µF
Gain	30/π
Drive Specifications	
Nominal power	3730 W

Voltage	460V
Frequency	50Hz
Stator resistance	1.115 Ω
Stator inductance	0.005974H
Rotor resistance	1.083Ω
Rotor inductance	0.005974H
Mutual inductance	0.2037H
No. of poles	4

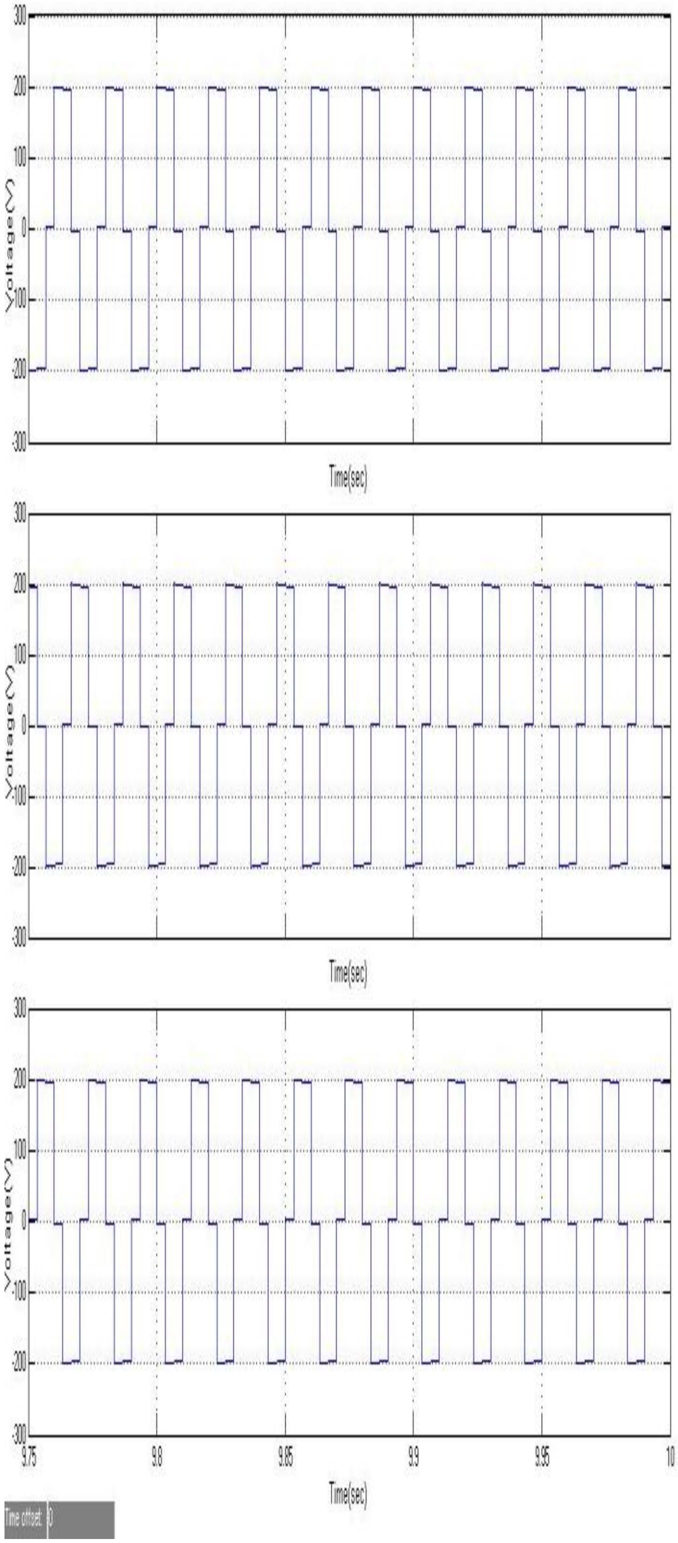

Figure.15. Simulation result of Inverter output Voltage

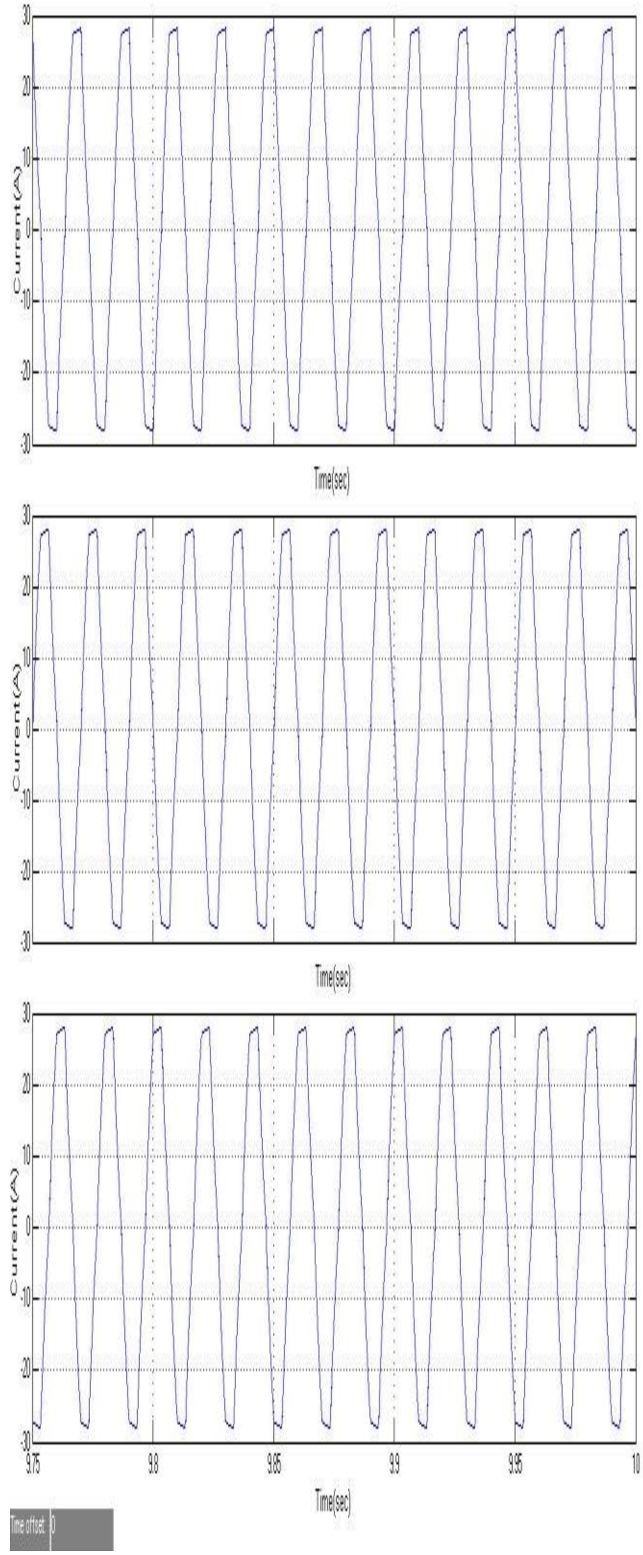

Figure.16. Simulation result of Inverter input current

Simulation model of proposed HESS system is shown in figure 14. Simulated results of proposed HESS system are shown from figure 15 to figure 17 respectively. Ratings of Proposed HESS system is given in Table.1.

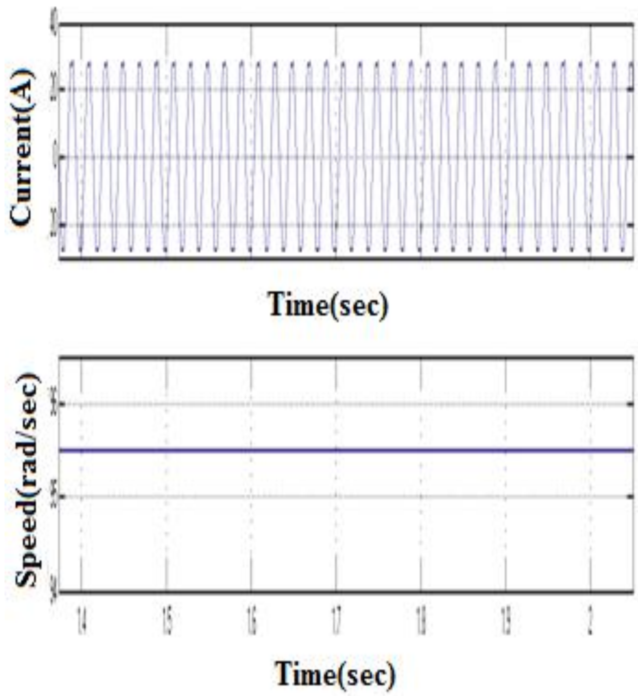

Figure.17. Simulation Result of Stator Current and Rotor Speed of BLDC motor

4. HARDWARE IMPLEMENTATION OF THE PROPOSED TOPOLOGY

To verify the operational principles of the proposed model, a prototype is implemented and tested. Experimental results validated proposed model and is given in Table.2.

Table.2 Comparison of Software and Experimental results

S. No	Parameter	Simulated Result	Experimental result
1.	Input voltage	120V	120V
2.	Output voltage (Acceleration mode)	240V	228V
3.	Output voltage (Retardation mode)	13.5V	13V

Figure.18 Hard ware Model of Buck Converter

Figure.19. Hardware Model of Boost Converter

Figure.18 & figure.19 shows the fabricated models of Boost and Buck Converters. Boost and Buck converters are incorporated in a proposed HESS for Electric vehicle and shown in figure.20.

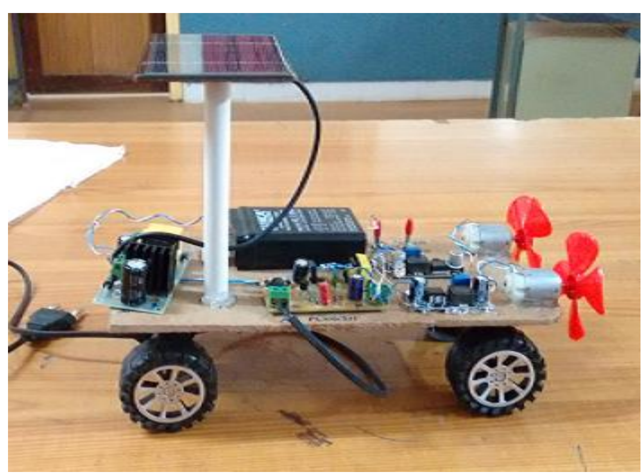

Figure.20. Hardware implementation of proposed HEMS model

5. CONCLUSIONS

In this paper, a novel Battery/Ultra-Capacitor based Hybrid Energy Management System along with motion control for Electric/Hybrid Electric vehicles has been proposed. The simulated results are validated experimentally by operating the proposed vehicle in different modes. The results are satisfactory and concluded that the proposed topology of hybrid energy management system is appropriate for Electric/Hybrid Electric vehicles and also charging at faster rate as well.

6. REFERENCES

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