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An Efficient Regenerative Braking System for Hybrid Electric Vehicle with BLDC Motor

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ABSTRACT: Increasing use of vehicles increases pollution. In order to control pollution one of the best way is to convert all the internal combustion engine vehicles to Electric vehicles or Hybrid electric vehicles. Here we have proposed a Hybrid energy storage system using a lead acid battery and a supercapacitor to store the regenerative braking energy using a regenerative braking system. The regenerative braking system is controlled by using ANN Controller and a Pi Controller helps to maintain constant torque and current during braking. During braking process the energy from the motor will be stored at the supercapacitor by taking suitable switching algorithms. The motor will act as a generator and it will charge the supercapacitor as well as the battery through the inverter. The energy stored at the super capacitor shall be used at the time of driving uphill and the result is demonstrated in MATLAB/Simulink.

KEYWORDS: Regenerative Braking System, Hybrid Energy storage system, Hybrid Electric vehicle, BLDC Motor, Artificial Neural Network

I.INTRODUCTION

VEHICLES are one of the most important thing in our day to day life. Increase in the vehicle usage increases the pollution overall the world. In order to reduce the pollution from the internal combustion engines used in vehicles we have started using electric vehicles. Electric vehicles have some key features like low emissions, high efficiency and quiet operation compared to other vehicles. There are many different types of EV's like Battery Electric vehicle, Hybrid Electric Vehicle etc.

Hybrid Energy Storage System (HESS) comprises of a wide varieties of topologies. Among these most widely researched is Battery/Supercapacitor topology. HESS of battery/supercapacitor is mainly used to utilize the advantage of both such as high power density and high energy density.

In this paper, a combination of Supercapacitor and a Lead-Acid battery is used as a HESS and is driven by a BLDC Motor. A supercapacitor is an electro-chemical capacitor which is having higher energy density when compared to other capacitors and it will increase the system efficiency. It has fast charging and discharging speed. Here an additional switching pattern is given to the inverter operation in order to reduce the additional power electronics interface. The regenerative braking system will directly harvest the energy by reversing the motor in to a generator.

II.HYBRID ENERGY STORAGE SYSTEM AND REGENERATIVE BRAKING SYSTEM

The Hybrid energy Storage System is a combination of Lead-Acid battery and Supercapacitor. A dc-link is directly connected to the battery and it will remain constant as the battery pack is having lower voltage. A DC-DC Buck converter is connected in between the supercapacitor and the battery. The supercapacitor and the battery is paralleled using a diode and a limiter switch. This is directly connected to the BLDC motor via Three phase inverter.

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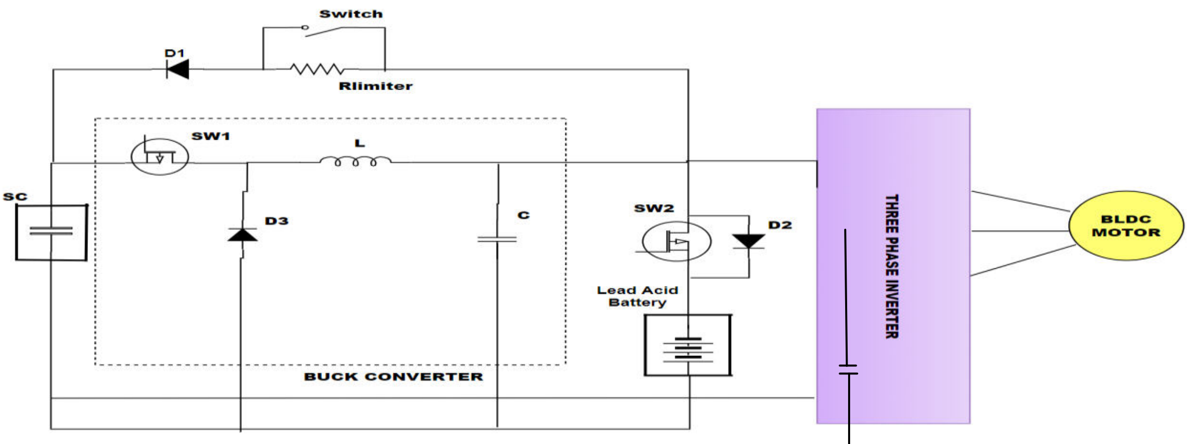

Fig.1 Hybrid Energy Storage System

Here we are using three modes of operations ie, Normal Driving condition, Acceleration or driving uphill, Regenerative braking Mode. In normal driving condition the battery alone will supply the BLDC motor through the buck converter. Here the diode will be reverse biased in order to keep the supercapacitor voltage higher than the battery pack. When driving uphill or in acceleration mode the power demand will be increased and the supercapacitor will also provide power along with battery to run BLDC motor. When it comes to regenerative braking the motor will be reversed as a generator by utilizing the MOSFETs in three phase inverter and the motor inductances. A switching pattern is given to the MOSFETs and inductances and a boost converter is formed. Then the dc-link voltage is boosted and the diode will be forward biased to charge the supercapacitor.

Supercapacitor is having a self discharging characteristics and it will destroy the hybrid energy storage system when it is not charged for a while. So in order to control the inrush current coming from the battery pack to the supercapacitor while regeneration a limiter resistance is given in series to the diode. When the supercapacitor is charged as of the battery then this limiter resistance will be turned ON using a mechanical switch provided. The diode D1 is short circuited and the limiter resistance will help the battery during normal condition.

According to the demand of power to the motor different modes of operation will carryon.

III. MODES OF OPERATION

A. NORMAL DRIVING MODE

The power demand of the motor will be equal or less than the battery pack. So in normal driving mode the battery alone will supply the power. In this mode of operation the buck converter is turned off and the diode is reverse biased the supercapacitor is having higher voltage than the battery pack. The energy flow is shown in fig;

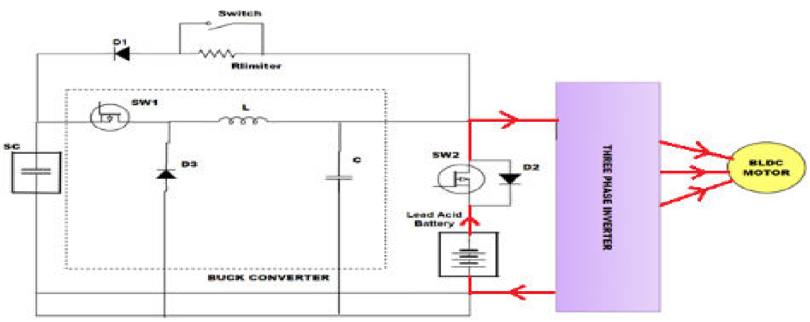

Fig.2 Vehicle Normal Energy Flow

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B. ACCELERATION MODE

The power demand of the motor exceeds the battery rated power and it is referred as the acceleration mode or driving uphill. The vehicle performance will be affected due to the frequent discharge cycles of battery pack. In this condition the supercapacitor will provide the power along with battery through the buck converter as the supercapacitor voltage is higher than the minimum threshold value. Here the supercapacitor will provide the power only till the voltage of supercapacitor is higher than battery in order to prevent the reverse flow. Hence the diode is reverse biased and the supercapacitor and battery pack is providing power to BLDC motor.

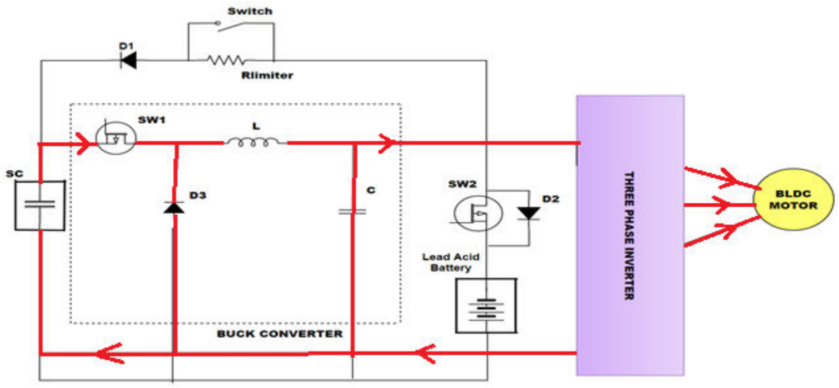

Fig.3 Vehicle Acceleration energy flow

C. REGENERATIVE BRAKING MODE

During braking condition the force applied on the brake pedal is usually generated as heat energy and additional cooling system will be required. In order to avoid the energy loss as well as the additional expenditure to the cooling system we are implementing a Regenerative Braking system to the electric vehicles. When we apply beak force to the pedal the energy from the braking will be harvested to the hybrid energy storage system by using the switching pattern to the lower switches of the inverter and the inductance of the motor. So that the diode is forward biased and the energy is stored in the supercapacitor. Here the additional switching devices are eliminated by using the switching patterns and by converting the motor as a generator during braking.

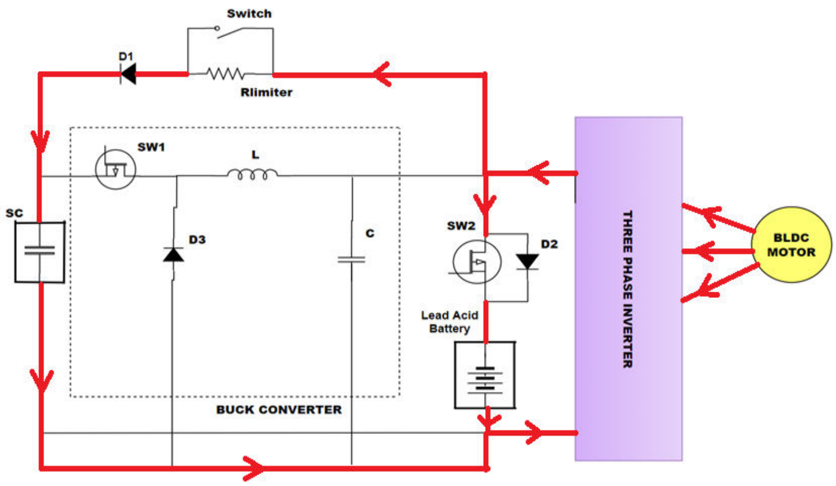

Fig.4 Vehicle Regenerative braking with battery and supercapacitor energy flow

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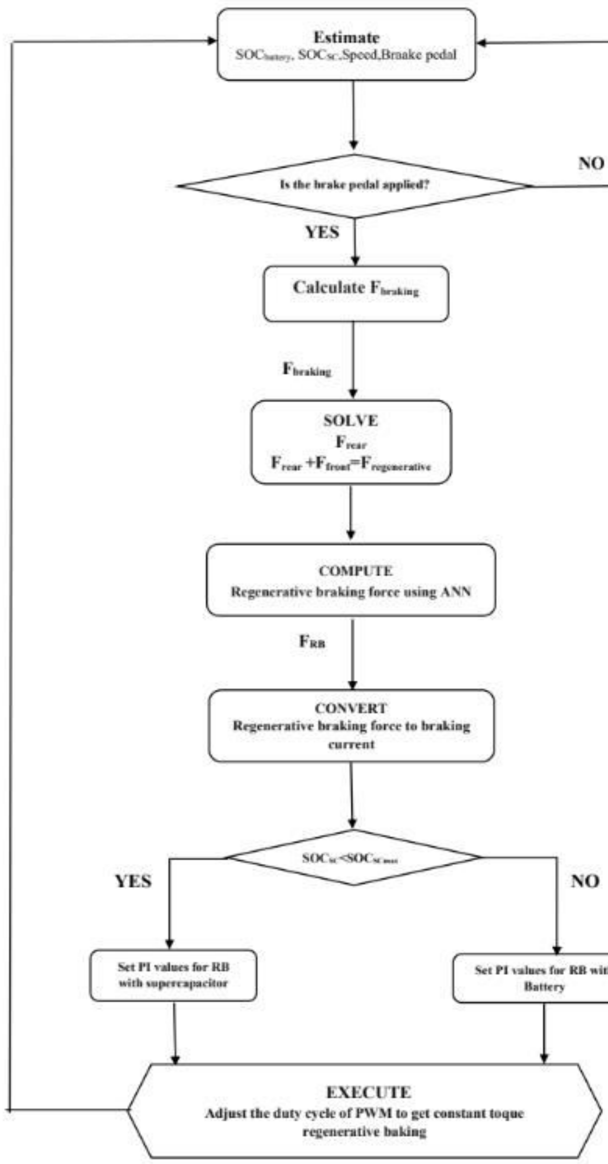
IV. ARTIFICIAL NEURAL NETWORKING

When we apply brake to the pedal, according to the amount of brake applied the force distribution will be calculated. The Artificial Neural Network based controller is used to calculate the force distribution at the rear and front wheels of the electric vehicle. The input and output patterns of this neural networks are determined by the multilayered neurons which consists of intelligent computing tools. Here we are using Multilayer perceptron and radial basis function. All the outputs will be completely based on the design processing. First step is to prepare a dataset with all the possible cases available. Second we have to structure our neural network according to the data given. Third we have to train the neural network with the collected data. At last we have to compare the dataset we gave given with another set of data to know the accuracy and efficiency of our system.
Here we have given four inputs to the neural network. We have given SOC of battery, SOC of supercapacitor, Speed and the Brake Pedal and the outputs where Rear Brake, Front Brake and the Regenerative Front Brake. Here we have used random numbers for training the dataset.



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V. METHODOLOGY

The modelling of the project is done in MATLAB/IMULINK. First we have simulated the BLDC motor with the specifications given in the table. Then we have simulated the Lead acid battery and it was connected in series to get the desired voltage. We have simulated a supercapacitor with certain specifications as given in the table and we have cascaded everything. Here a supercapacitor and lead acid battery is connected using a buck converter and a diode to form a Hybrid Energy Storage System. A new braking system was developed in this work. In normal driving condition the battery alone will supply the motor via three phase inverter. During peak power demand or driving uphill condition the supercapacitor will also provide power along with the lead acid battery through buck converter. Here we have to maintain the voltage of supercapacitor higher than that of battery pack. A power converter is used to maintain the voltage level of the supercapacitor and battery and hence the diode will be usually reverse biased. The main purpose of regenerative braking system is to conserve energy. From the law of conservation of energy we know that energy can neither be created nor be destroyed, but can be transformed from one phase to another.

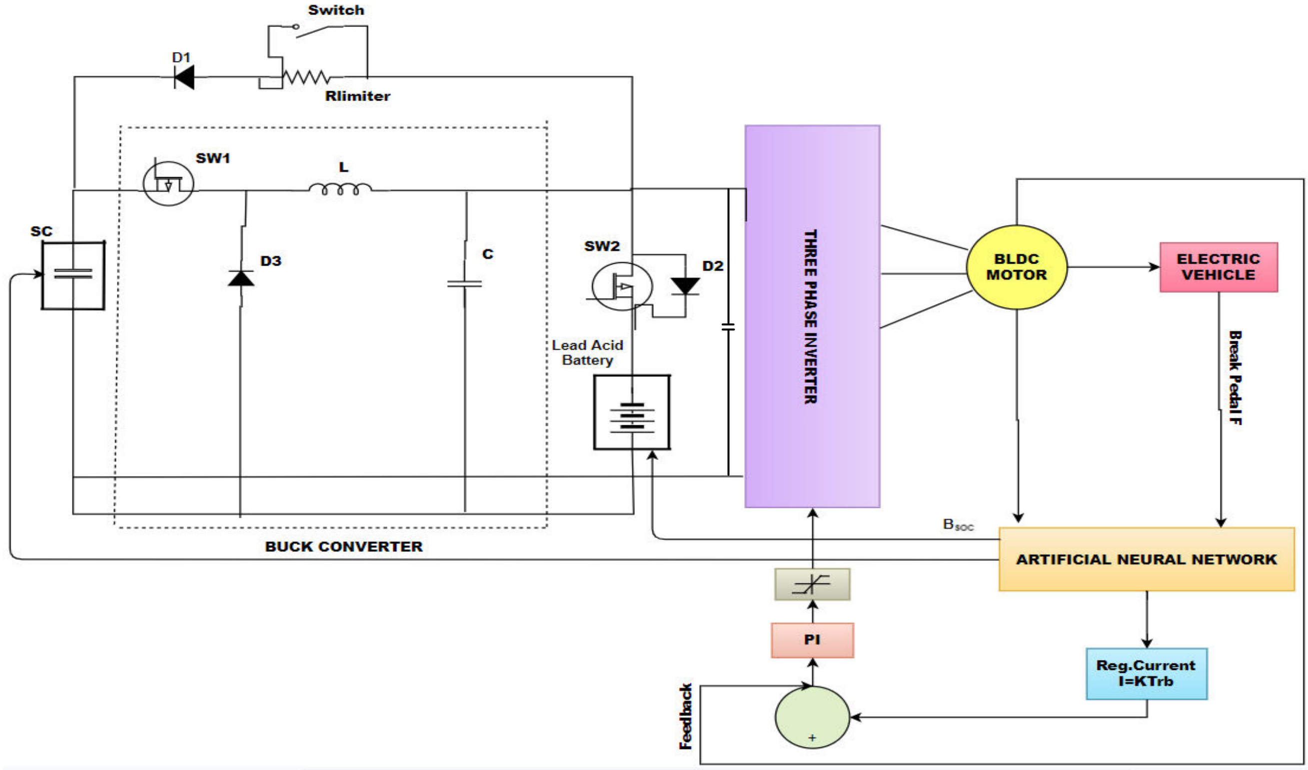

Fig.5 Regenerative Braking System With Hybrid Energy Storage System

During braking condition the heat energy released can be converted in to electrical energy which can be saved in supercapacitor or lead acid battery. Here the motor will act as a generator and the MOSFET's in three phase inverter and the motor inductances will form a suitable switching pattern and will boost the chopper. So the dc link voltage will get boosted and the diode will get forward biased. So that the braking energy is effectively used to charge the supercapacitor as well as the battery. Due to the self discharge characteristics of the supercapacitor the voltage across the supercapacitor will decay itself if the hybrid energy storage system is not charged for an instant. The diode D1 will be forward biased at that time and switch SW2 will be ON. There will be a high current flowing from battery to supercapacitor which will damage the whole system.

In order to solve that problem we have connected a limiter resistance in series with the diode. When the supercapacitor is charged to a level of battery the limiter resistance will be bypassed using a mechanical switch.

An artificial neural network is used to calculate the force distribution and a PI Controller is used to adjust the braking current and toque to maintain them as constant.

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VI. SIMULATION AND RESULTS

HYBRID ENERGY STORAGE SYSTEM

In hybrid energy storage system we have connected a supercapacitor lead acid battery a three phase inverter and a BLDC motor. Here we have only simulated a single cell battery with 12v for this hybrid energy storage system and verified weather it is working under Normal condition and acceleration Condition.

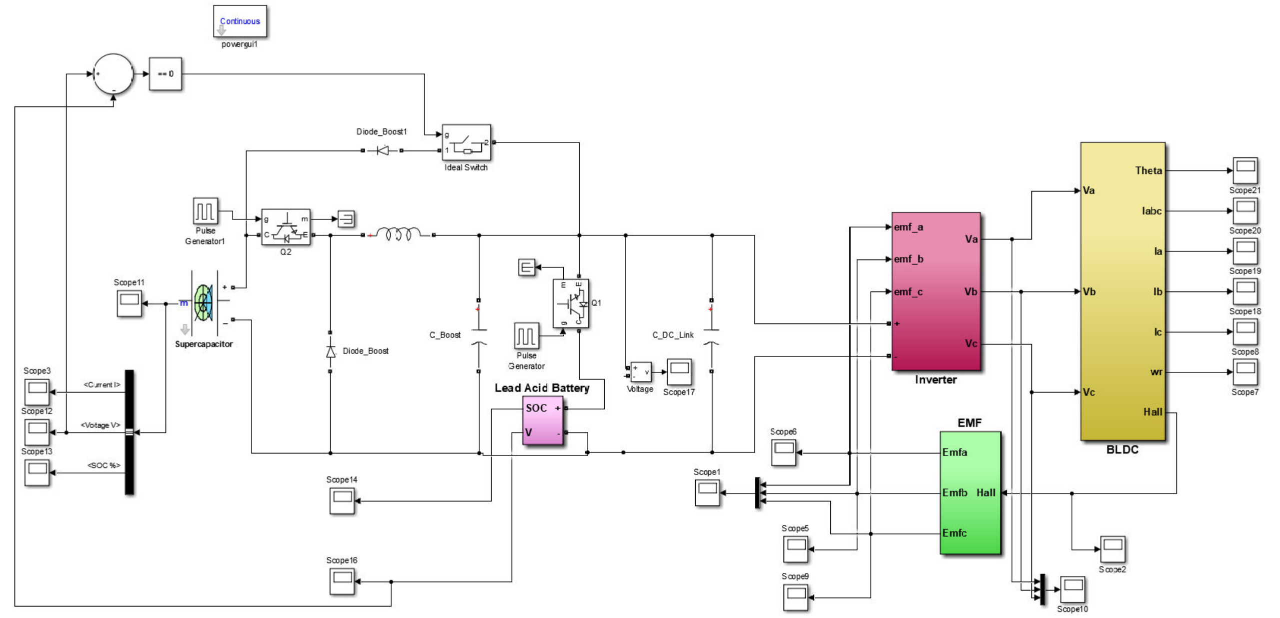

Fig.6 Simulation model of Hybrid Energy Storage System

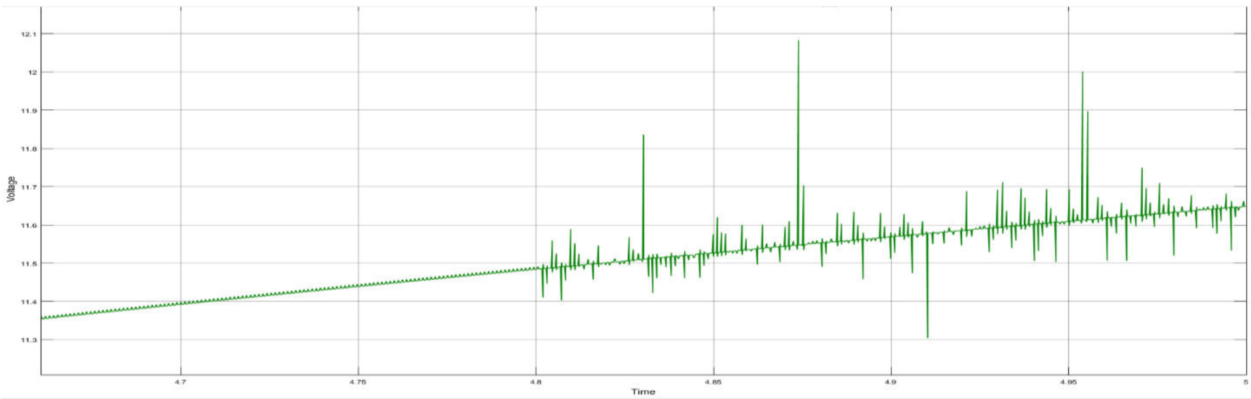

Fig.7 Voltage of the Battery

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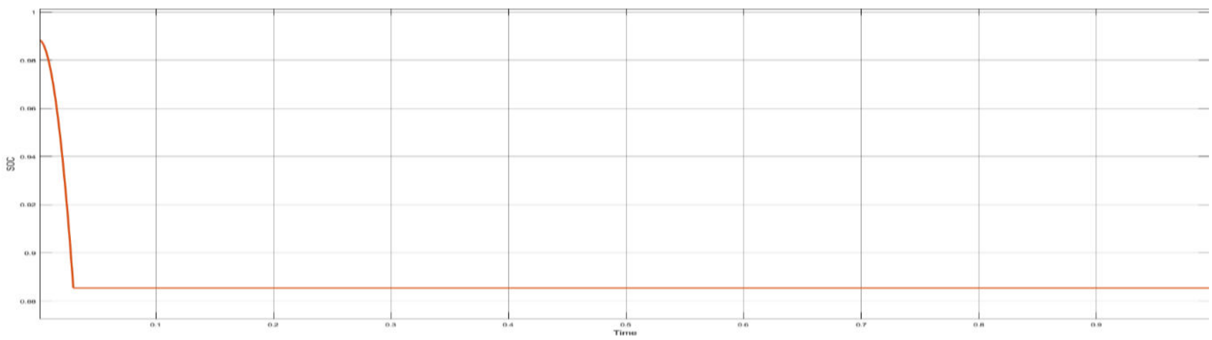

Fig.8 SOC of Battery

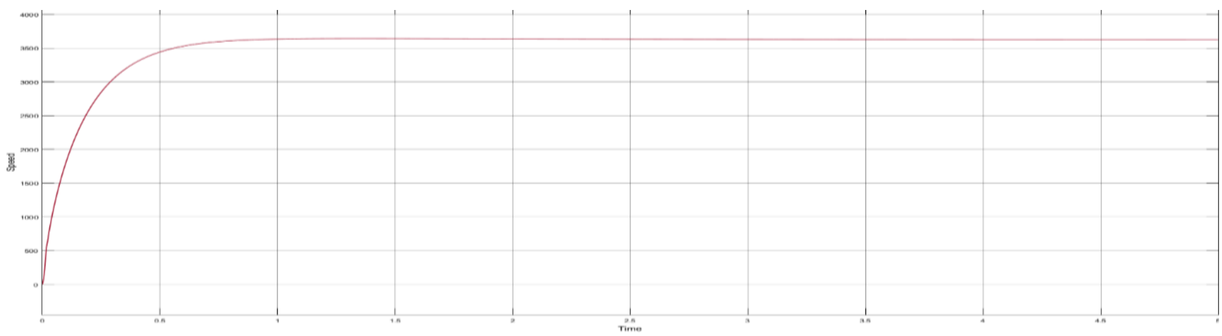

Fig.9 Speed of the BLDC Motor

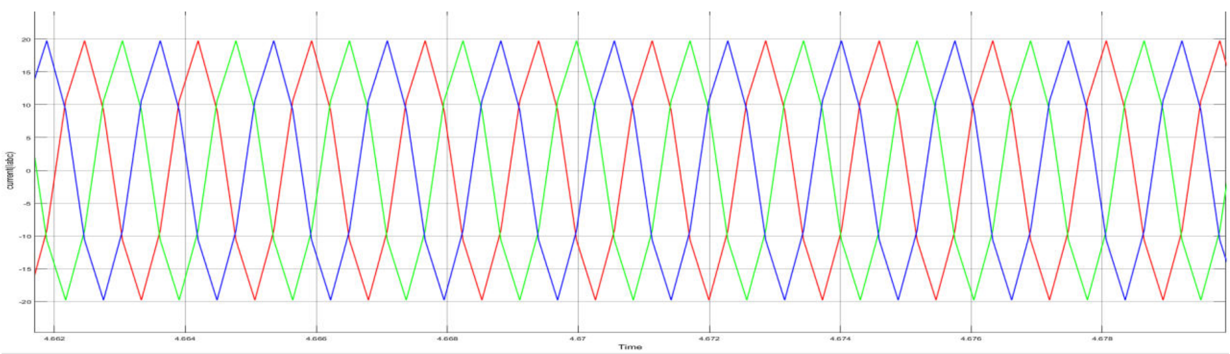

Fig.10 Current Of BLDC Motor

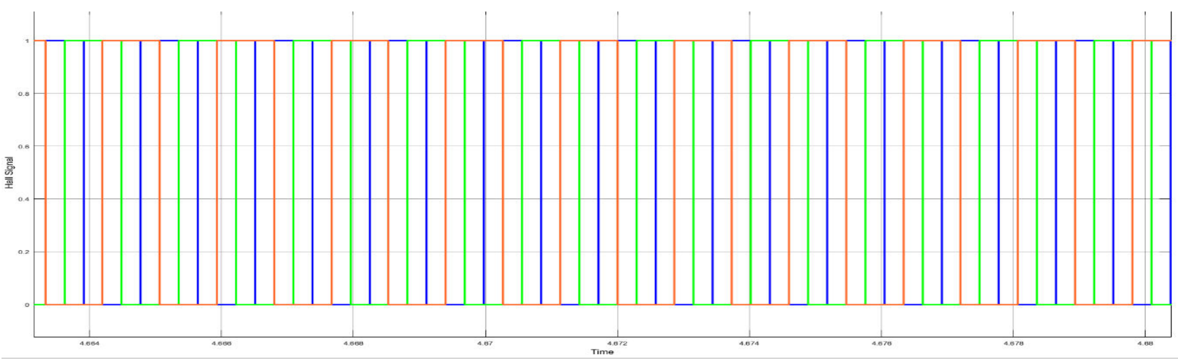

Fig.11 Hall Effect Signal

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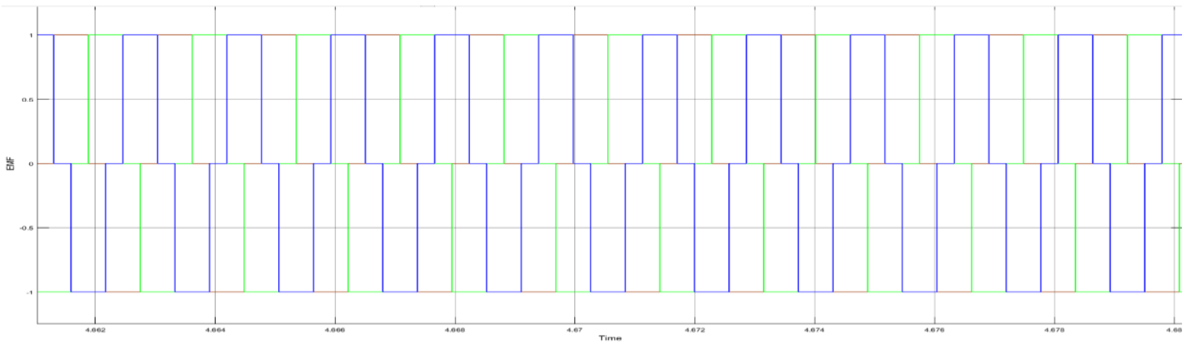

Fig.12 Back EMF of Motor

REGENERATIVE BRAKING SYSTEM USING HYBRID ENERGY STORAGE SYSTEM

The proposed Regenerative Braking System is modelled using MATLAB/SIMULINK. A drive cycle with three different modes was given to the simulation. We have given 0 to 0.3 under Normal driving condition and 0.3 to 0.6 under Acceleration condition and 0.6 to 1 as Regenerative Braking condition.

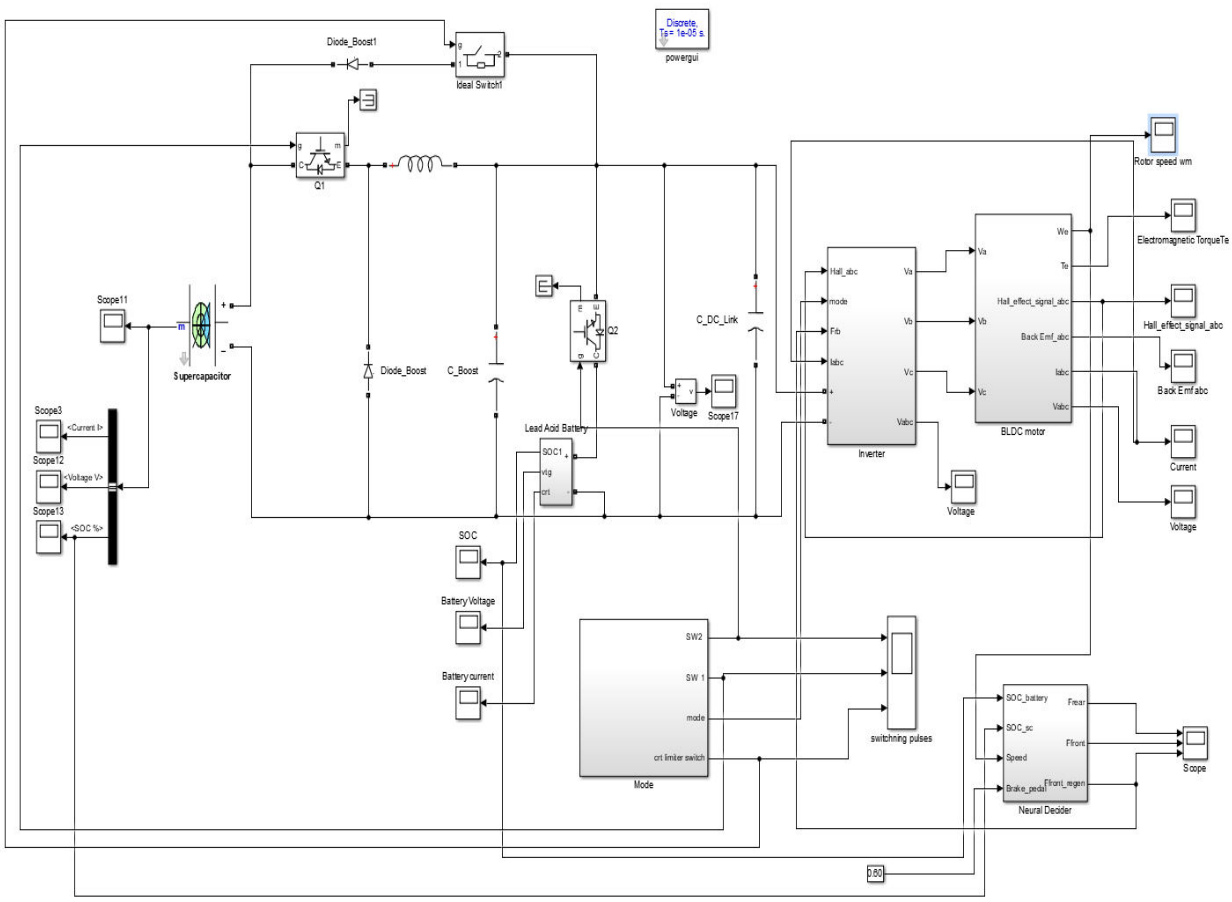

Fig. 13 Simulation Model Of Regenerative Braking System with Hybrid Energy Storage System

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TABLE I

PARAMETER	VALUES
Phase Resistance	1.43 Ohm
Flux	0.2158 Wb
Rated Power	4.8 KW
Supply Voltage	220v
Current	22A
Speed	5650rps

SPECIFICATION OF BLDC MOTOR

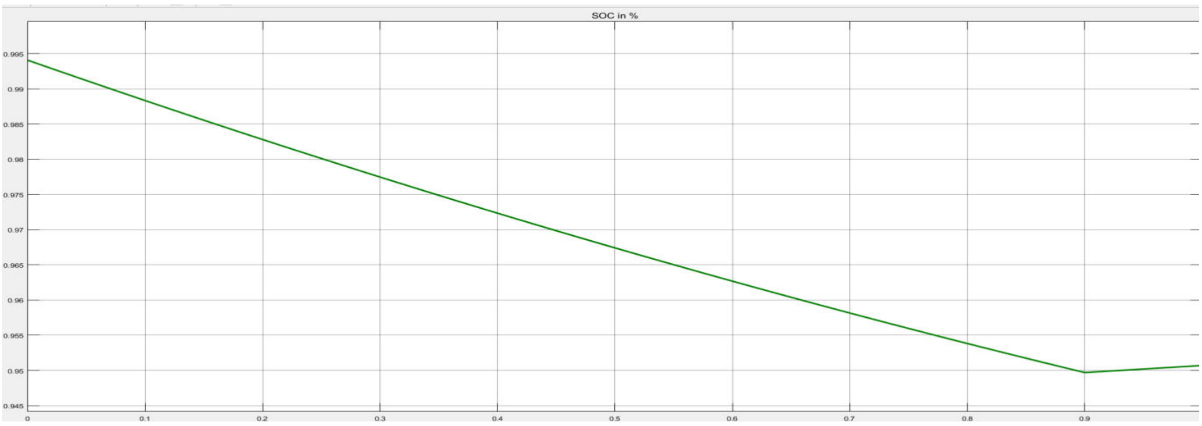

Fig.14 SOC of Lead Acid Battery

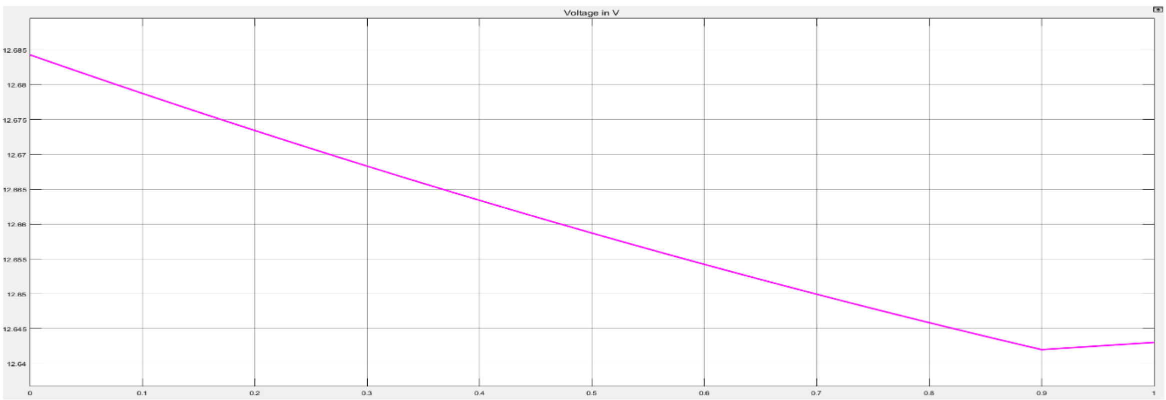

Fig.15 Voltage of the Lead Acid Battery

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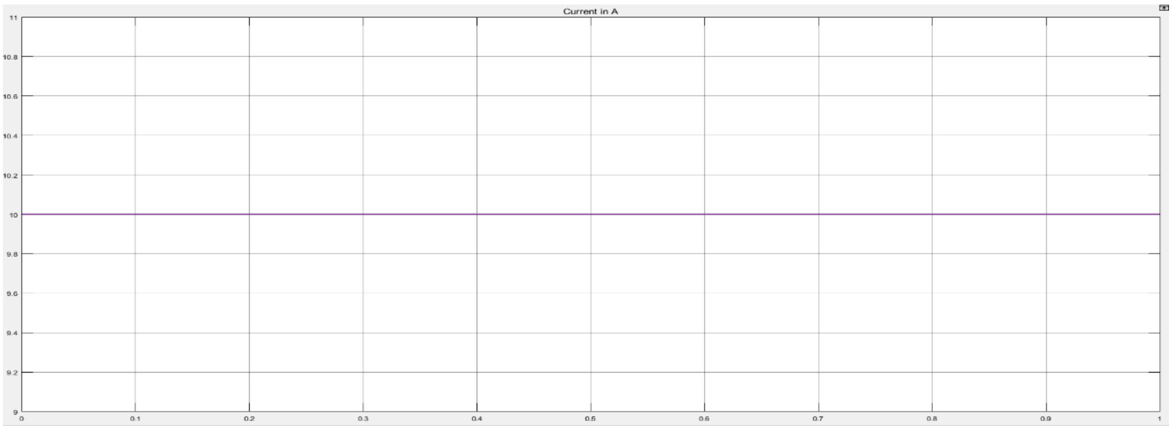

Fig.16 Current of Lead Acid Battery

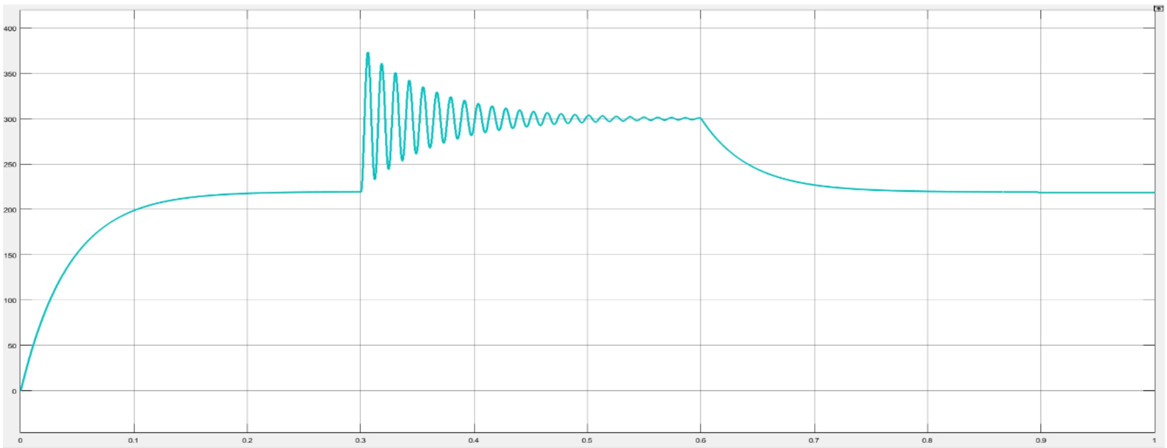

Fig.17 DC-link Voltage

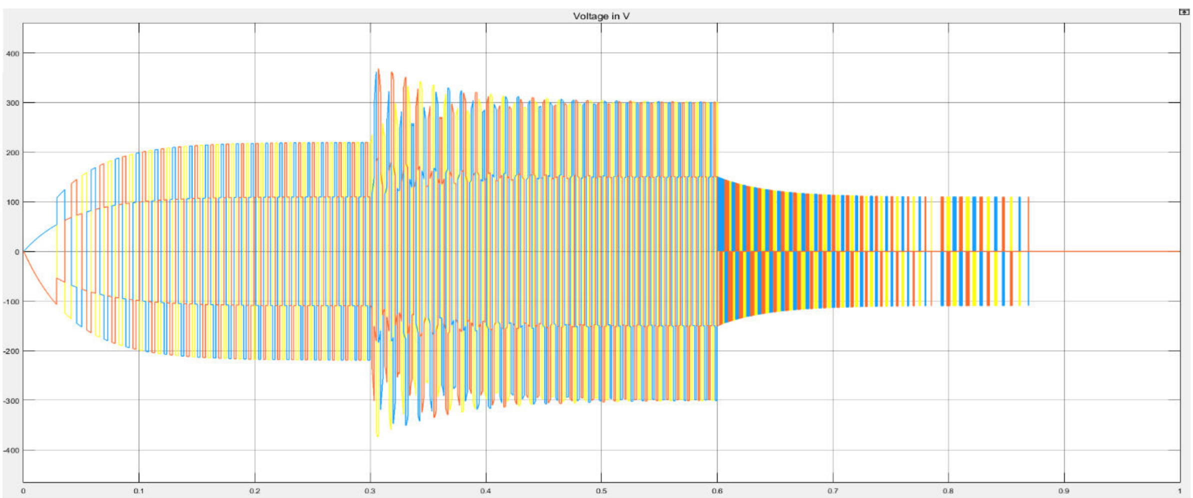

Fig.18 Inverter Output Voltage

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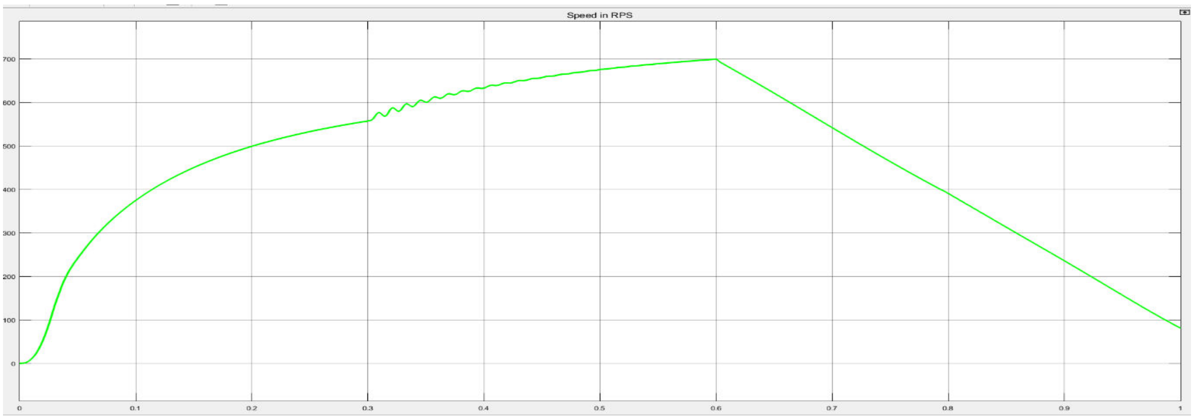

Fig.19 Speed of BLDC Motor

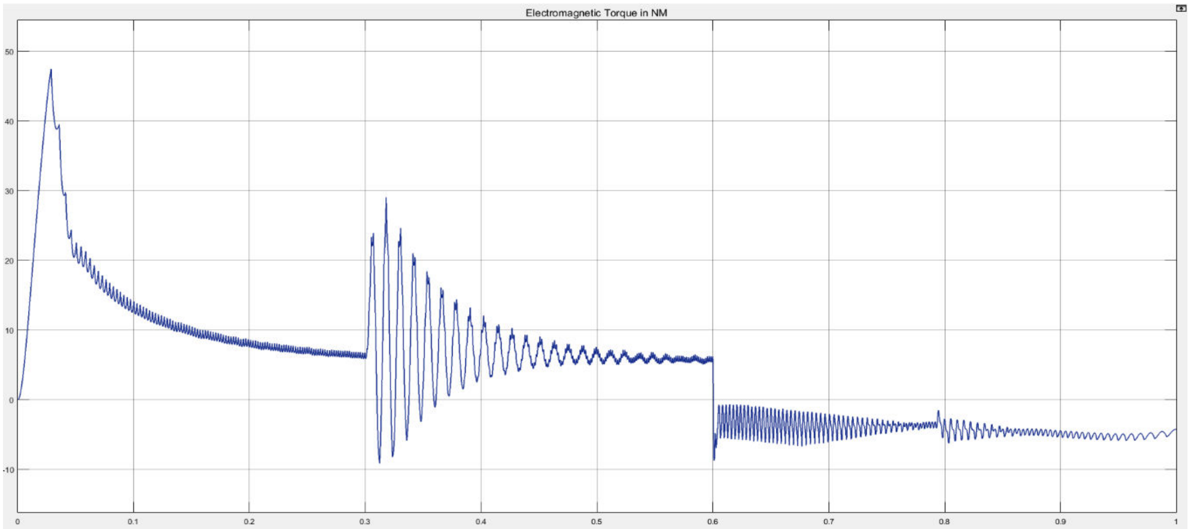

Fig.20 Electromagnetic Torque of BLDC Motor

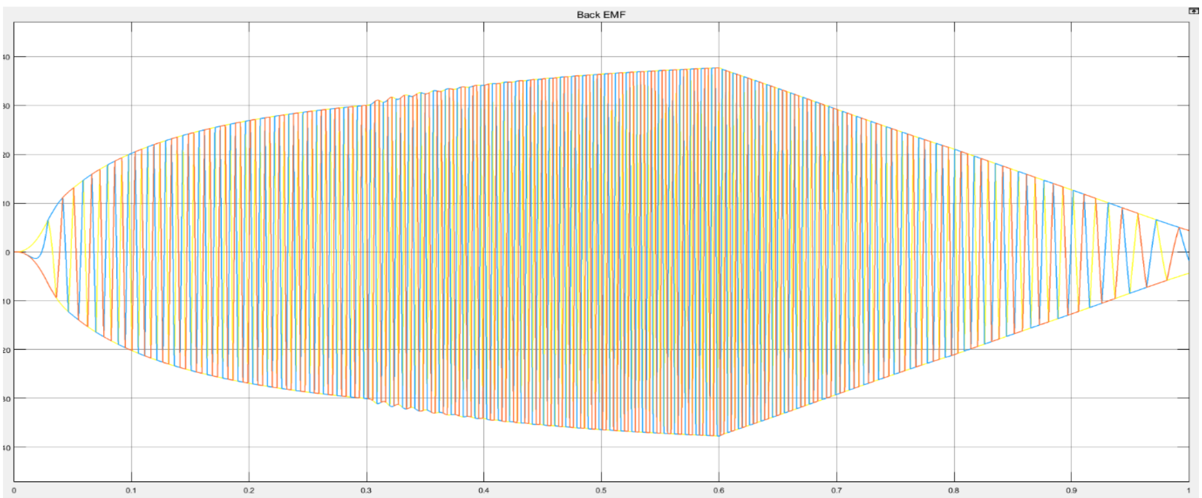

Fig.21 Back EMF of BLDC Motor

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Fig.22 Hall Effect Signal

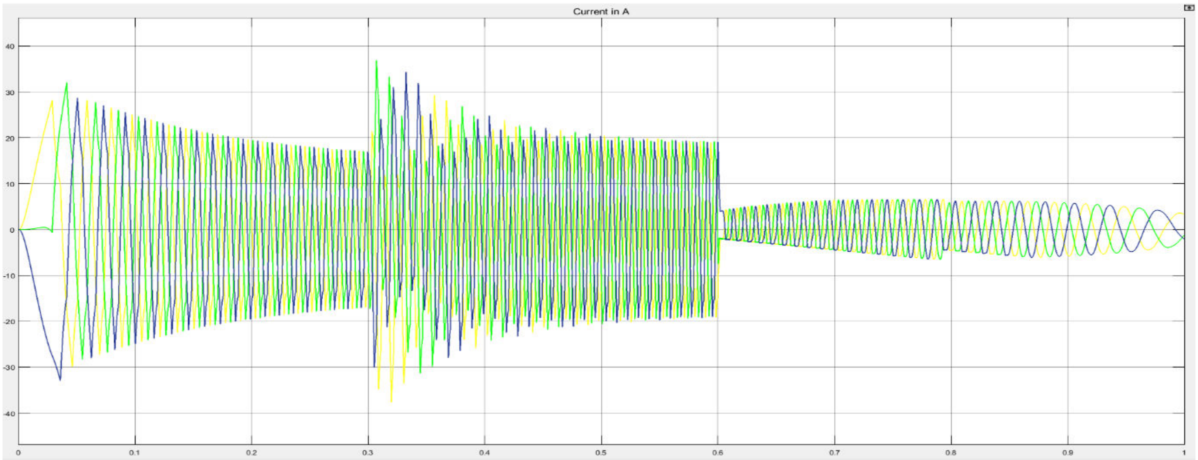

Fig.23 Current Waveform

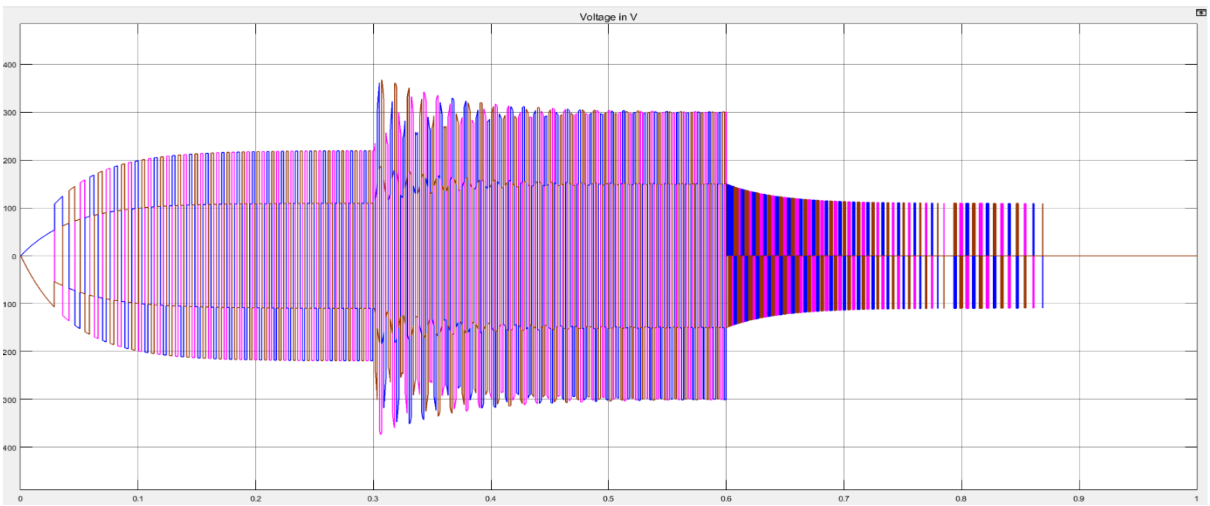

Fig.24 Voltage of the BLDC Motor

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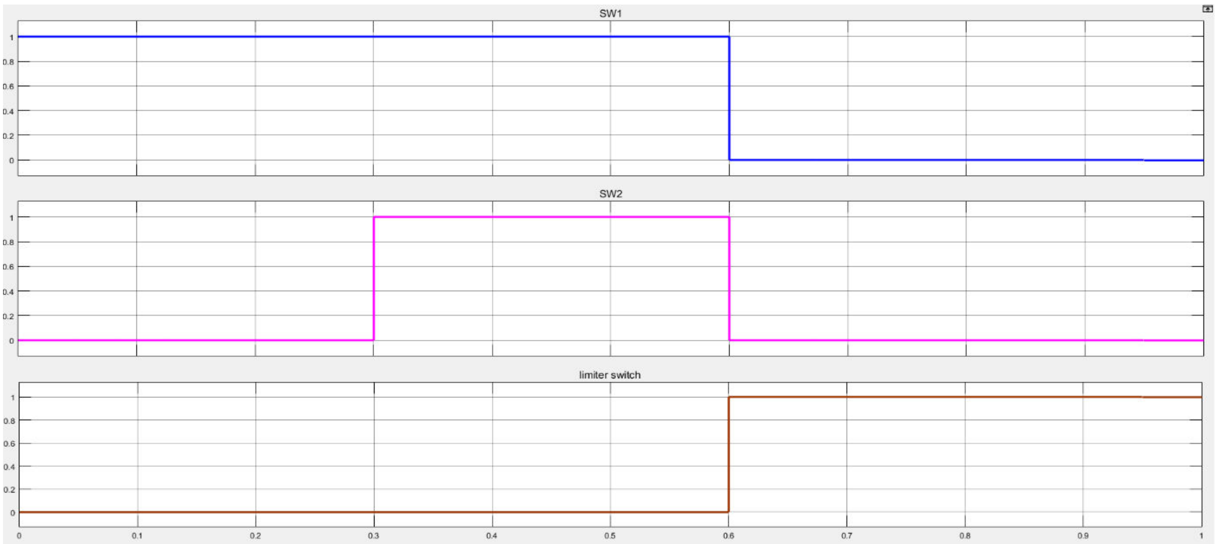

Fig.25 Switching Modes

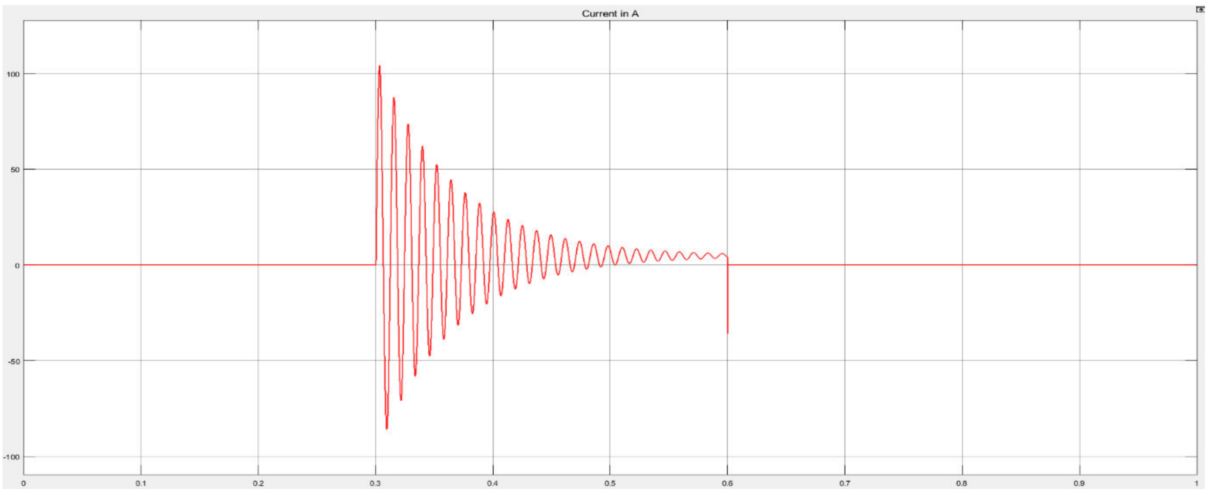

Fig.26 Current of the Supercapacitor

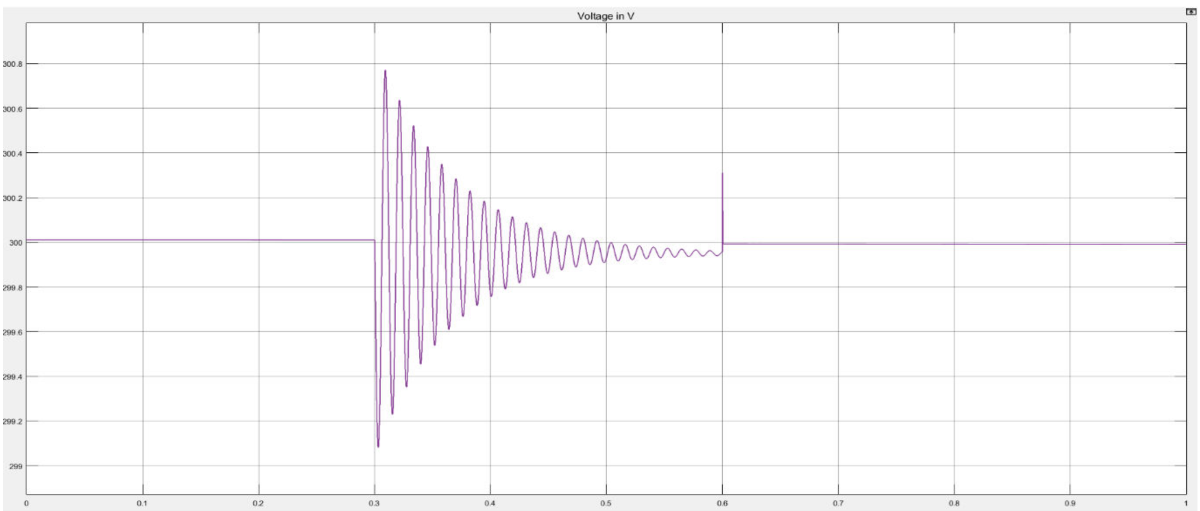

Fig.27 Voltage of Supercapacitor

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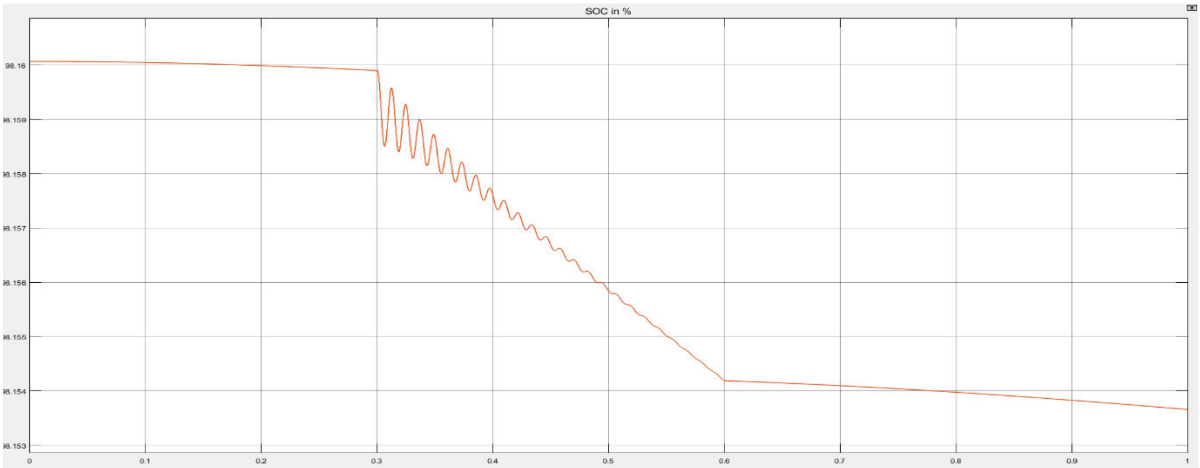

Fig.28 SOC of Supercapacitor

VII.CONCLUSION

Here a new Regenerative braking system based on the utilization of Hybrid energy storage system for hybrid electric vehicle driven by BLDC motor is proposed. During Regenerative braking the kinetic energy of the vehicle is harvested by the supercapacitor by using appropriate switching pattern of the inverter.Therefore the need of additional power electronic devices is eliminated.The MLP-ANN is used to control the braking force distribution between the front and the rear wheels.The PI controller will control the duty cycle of the PWM of the inverter to realize the constant toque in braking.By comparing the other braking schemes the proposed method has superiorities of being simple and high efficient.This ensures the safe deceleration of the electric vehicle.

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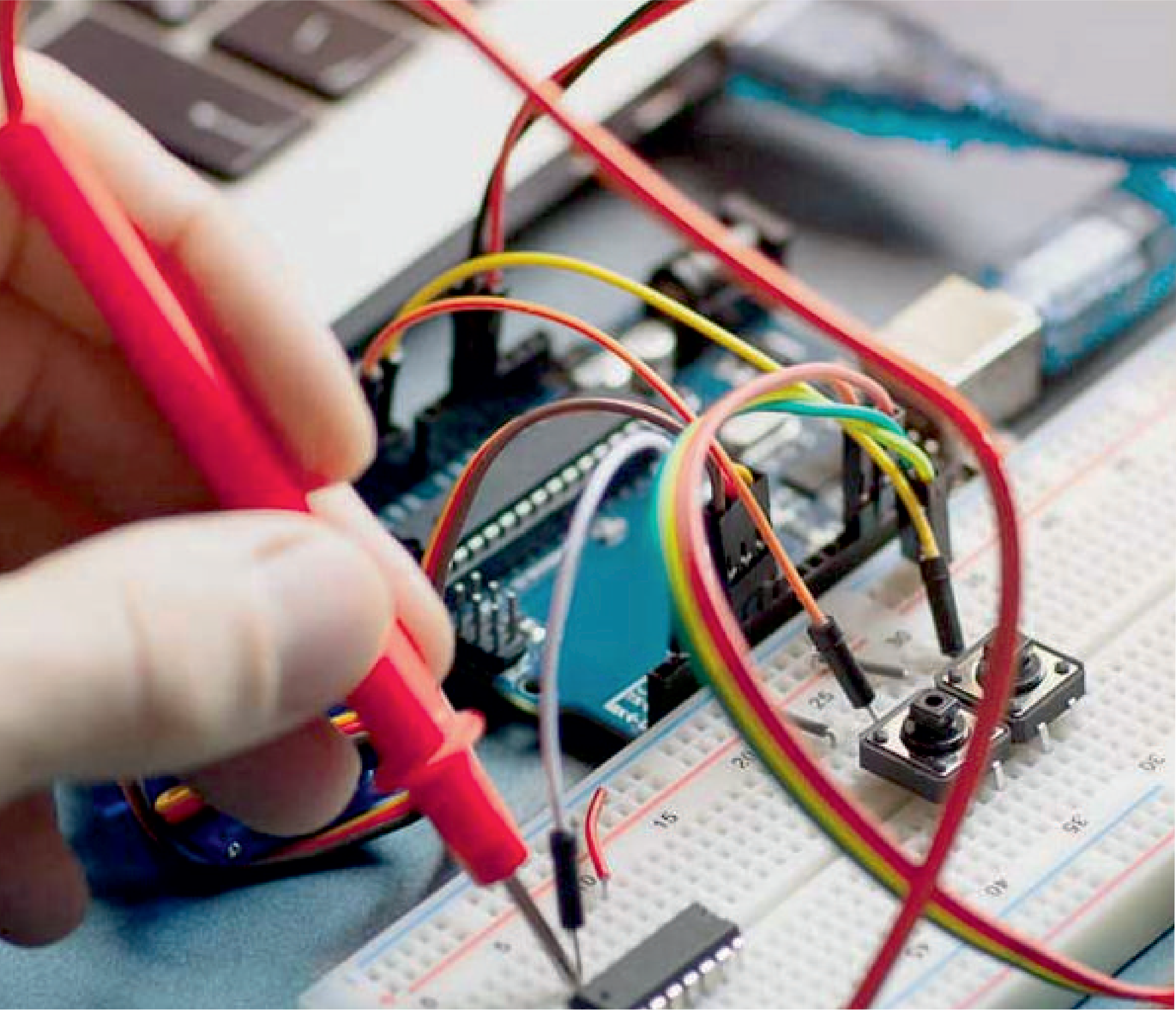

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