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A Novel Method of Energy Regeneration in Electric Vehicle

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Abstract: This paper proposes a novel regenerative braking scheme for electric vehicle driven by brushless dc motor and uses a new control technique to utilize regenerative braking energy effectively and uses fuzzy logic to utilize regenerative braking energy effectively. Drawback of electric vehicle is that long travelling, distance covered between two charging stations, less accelerating power during uphill driving. The fuel efficiency and driving range of electric vehicle can be improved by regenerative braking energy. To provide smooth brake, the electric brake distribution is realized through Fuzzy Logic Controller (FLC). The battery has high energy density however low power density yet super-capacitor has low energy density yet high power density. Keeping in mind the end goal to conquer the faults a battery super-capacitor crossover energy stockpiling framework is utilized. During uphill driving the electric vehicle requires more power for climbing, according to the load and required power a hybrid super-capacitor battery energy storage system is switched. To control motoring and braking in electric vehicle several bidirectional converters are used to integrate batteries and super-capacitors. The braking action in regeneration is much affected because of discontinuous input current at motor end and regenerative braking failure at lower back-EMF.

Keywords: Brushless DC Motor (BLDC), EV (ElectricVehicle), Fuzzy Logic Contol (FLC), HESS (Hybrid Energy Storage System), Regenerative Braking Energy (RBE), State Of Charge (SOC).

I. INTRODUCTION

Among all type of energy sources fossil fuels are most desirable type and this kind is going to be finished. Some issues such as global warming and environmental pollutions are the effects of fossil fuel usage [1]. It is important to find other ways to reduce energy consumption and reuse wasted energy. The electrical energy can be converted from kinetic energy during braking process [2]. Regenerative braking energy can be converted by power electronic devices into electrical energy. An efficient energy storage system not only reduces the fuel consumption but also stabilizes the line voltage and reduces the peak input power, resulting in lower losses. The best way to regenerative braking energy is super-capacitor-battery HESS. From the figure1 we can see the qualitative comparison of super-capacitor and battery. In this figure comparing different factors such as safety, price(per kWh), price (per kW), energy density, power density, temperature range, recyclability, absolute tolerance, self-discharge (% day), cell voltage and recyclability of super-capacitor and battery. Each source has its own advantages and disadvantages, by combining these two sources demerit of one can be rectify by the other. The use of HESS has numerous points of interest, for example, high power density of super capacitors can be utilized to viably outfit the kinetic energy of vehicle amid braking. Super-capacitor can help the battery pack in top power requests which drags out the battery life time, as well as enhances the vehicle acceleration. Since the braking energy could be effectively saved, the vehicles driving range can be considerably increased [3]. . The motor terminal voltage and voltage level of sources is different in electric vehicle. The batteries and super-capacitors are operated at low voltage level. To improve efficiency the motor unit is operated at high voltage level.

Due to lower back EMF, the amount of power drawn from motor unit through regenerative braking is limited. When motor terminal voltage reduces lower than source voltage at that instant traditional power converter fails to extract power at regenerative braking mode.

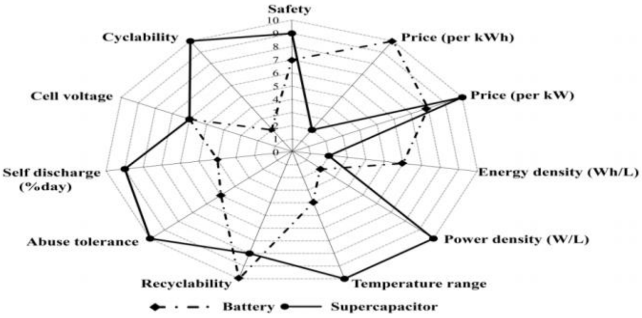

Fig. 1.Qualitative comparison of super-capacitor and battery

By analyzing the factors of the regenerative braking, the mamdani fuzzy logic controller (FLC) is developed. Model based on fuzzy logic control was developed under the Matlab /Simulink environment.

II. PROPOSED SYSTEM

Through the depression of brake pedal and accelerator, the driver block delivers the desired brake torque and drive torque. Drive torque request is send to the vehicle through various drive train mechanism, battery and motor, according to the rate of depression of accelerator pedal. Brake torque request is send to the vehicle, according to the depression of brake pedal. The regenerative brake control methodology is isolated into two, regenerative braking and friction braking [4]. The aerodynamic friction losses, rolling friction losses, and the energy dissipated in the brakes have an adverse effect on the amount of mechanical energy consumed by a vehicle when driving a pre-specified driving pattern. Figure 2 shows the proposed system for regeneration of energy in electric vehicle. Here fuzzy control logic is used , it is a nonlinear control algorithm the main significance of fuzzy in this paper is that the state of charge of battery, speed and electric brake force distribution (EBD) are changing nonlinearly. For providing smooth brake EBD is realized through fuzzy. In this work input of the fuzzy are state of charge of battery (SOC),EBD, and speed. The output is the ratio of rear braking force and the total braking force; it is then converted to current. The current from the BLDC motor and controlled current are compared and that is given to the PID controller, duty cycle is adjusted to charge/ discharge the battery and/ or super-capacitor.

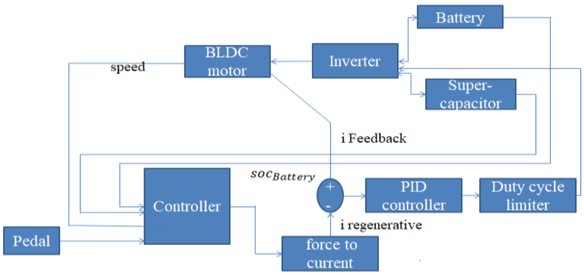

Fig. 2.Proposed System

A. Proposed hybrid energy storage system

Figure 3 shows the proposed hybrid energy storage system. Whenever the motor power is equal or less than the battery rated power, the vehicle normal mode is activated. The energy flow in the normal mode is In this mode, since the super-capacitor voltage is higher than the battery voltage, is reverse biased. Moreover, the buck converter is turned off and the super-capacitor module is idle. The battery pack solely supplies the BLDC motor in this condition.

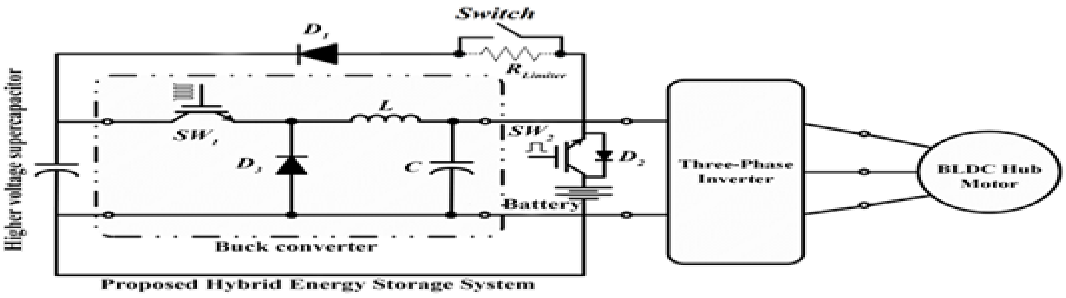

Fig.3. Proposed HESS

During the vehicle acceleration, driving uphill and vehicle top speeds, the motor power exceeds the battery rated power which here is referred to vehicle acceleration mode. Under such circumstance, the battery pack could undergo frequent deep discharge cycles and the performance of the vehicle could also be degraded. In such conditions, if the super-capacitor voltage is greater than the minimum threshold voltage, the super-capacitor starts to assist the battery pack through the DC-DC converter. If voltage of super capacitor falls below battery voltage in these conditions, the battery pack could unwantedly charge the super-capacitor module which increases the stresses in the battery pack. Therefore, super-capacitor only keeps assisting the battery pack until voltage of super-capacitor is higher than battery voltage. In such conditions, diode 1 is always reverse biased and the energies of both the super-capacitor module and the battery pack are supplying the BLDC motor.

Due to the voltage strategy of the super-capacitor and battery, diode1 is usually reverse biased in normal conditions. In the regenerative braking events, the DC-link voltage must be boosted so that diode 1 is forward biased and the braking energy could be harvested by the super-capacitor module. This is normally achieved by employing additional boost converters or substituting a bi-directional buck-boost DC/DC converter. Adding another DC/DC converter not only increases the implementation cost, but also decreases the energy transfer efficiency due to the power dissipation of the power electronics interfaces. One cost-effective idea is that by utilization of the inductances in the three-phase BLDC motor, the bidirectional switches in the three-phase inverter and employing suitable switching scheme, the inverter can form a boost circuit. The MOSFETS on the high arms of the H-Bridge are turned off and the MOSFETS of the low side are pulse width modulated. It should be noted that this mode of operation is activated only if voltage of super-capacitor is less than or equal to maximum voltage of super-capacitor, the super-capacitor module that is usually considered for safety of the operation.

III. VEHICLE DYNAMICS

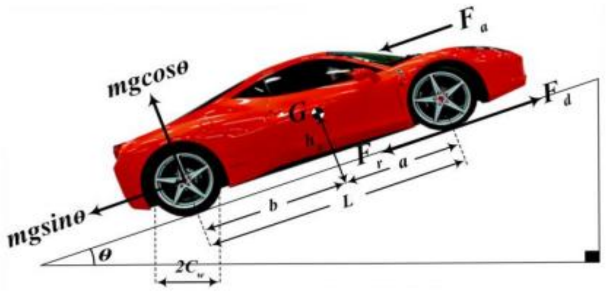

Fig.4 .Forces acting on Electric Vehicle during acceleration

Total force $=F_d - [F_r + F_a + F_g]$……….[1]

$F_d - [F_r + F_a + F_g] = km\frac{dv}{dt}$…………..[2]

Where F_r = Rolling resistance

F_a = Air Friction

F_g=Gravitational resistance

m= Mass

$\frac{dv}{dt}$= Acceleration due to gravity

F_g= mgsinθ……………..[3]

where θ is the slope

F_a is proportional to frontal area (A), and air density (ρ)

F_a α A×ρ……………..[4]

F_a α Aρ$(V + V_a)^2$ … …..……..[5]

Where V= Velocity of vehicle

V_a = Velocity of air

$$F_a = \frac{1}{2} c_a \rho (V + V_a)^2 \ldots\ldots\ldots\ldots\ldots [6]$$

c_a=0.2 to 0.4

A. Design of propulsion system with respect to velocity

$$F_a = \frac{1}{2} c_a \rho (V + V_a)^2 \mathrm{sgn}(v) \ldots\ldots\ldots\ldots\ldots [7]$$

When wind blowing in opposite direction

$$F_a = \frac{1}{2} c_a \rho (V - V_a)^2 \ldots\ldots\ldots\ldots\ldots [8]$$

Frictional force = c_f ∗mg

Frictional force for a vehicle moving in slope =c_f ∗mgcosθ

B. Maximum Gradability

Maximum gradability is obtained from certain assumptions such as no wind is blowing, frictional force is zero, and rolling resistance is zero.

$$F_d - [F_r + F_a + F_g] = \mathrm{km}\frac{dv}{dt} \ldots\ldots\ldots\ldots\ldots [9]$$

$$F_d = F_g \ldots\ldots\ldots\ldots\ldots [10]$$

$$F_d = \mathrm{mgsin}\theta \ldots\ldots\ldots\ldots\ldots [11]$$

$$\mathrm{Sin}\theta = \frac{F_d}{mg}$$

$$\theta = sin^{-1}\left[\frac{F_d}{mg}\right]$$

$$\tan\theta = \frac{F_d}{\sqrt{(mg)^2 - (F_d)^2}} \ldots\ldots\ldots\ldots\ldots [12]$$

IV. THE STRUCTURE OF FUZZY LOGIC CONTROLLER

A. The structure of FLC

Mamdani fuzzy controller is opted here because of its high operational efficiency, coordinates with linear control theory, employs adaptive technology and ensures output plane continuity. As per the impact components of regenerative braking, the FLC framework essentially includes three principle subsystems i.e. FLC input fuzzy variables, output fuzzy variables, and the fuzzy rules. The input variables are the driver's required braking force, vehicle speed and batteries SOC (State of Charge) and output variable is the ratio between the regenerative braking force and the total braking force [8]. The structure of FLC is shown in Fig. 4.

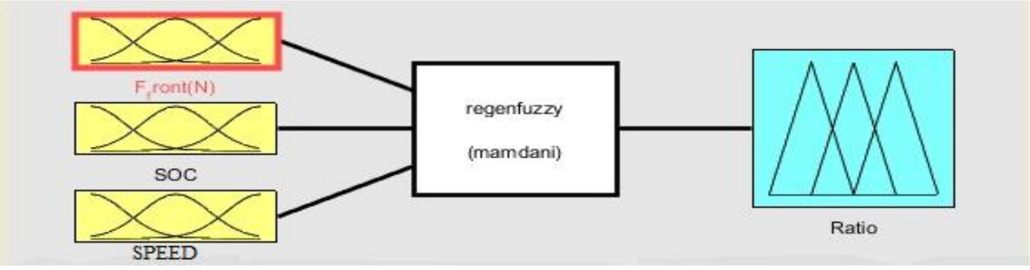

Fig. 5.Structure of FLC

B. Input/ Output membership Functions

Figure 6 shows the membership functions for one of the input force. We cannot determine the accurate range of membership functions and assuming the membership functions as low, middle and high and universal discourse is [0,1].

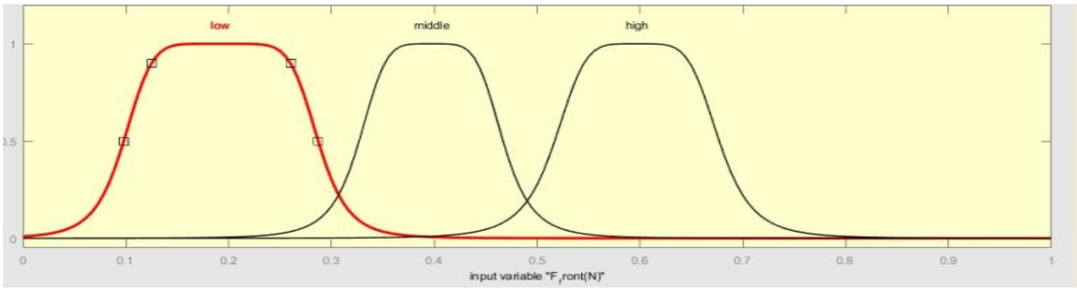

Fig. 6.Membership functions for force

Figure 7 shows the membership functions for one of the input SOC. We cannot determine the accurate range of membership functions and assuming the membership functions as low, middle and high and universal discourse is [0,1].

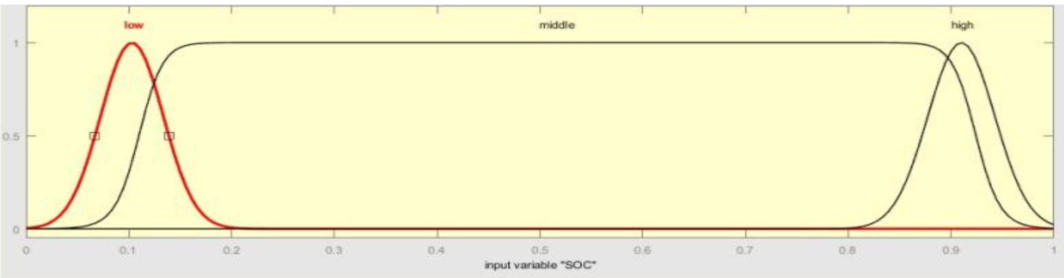

Fig. 7.Membership function for SOC

Figure 8 shows the membership functions for one of the input speed. We cannot determine the accurate range of membership functions and assuming the membership functions as low and high and universal discourse is [0, 3000].

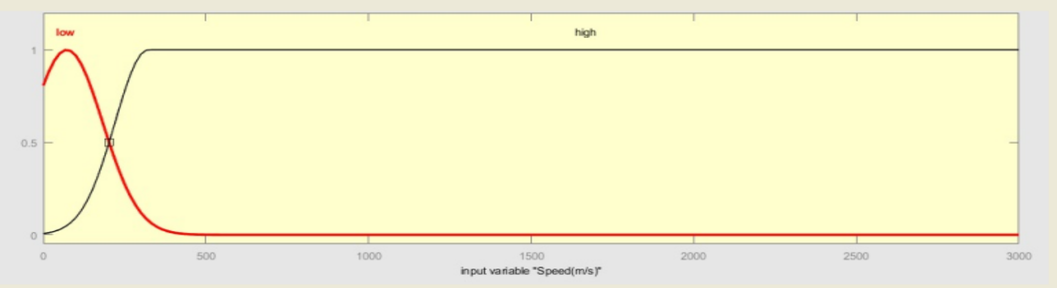

Fig. 8.Membership function for SOC

V.SIMULATION AND RESULTS

Figure 9 shows that the MATLAB/Simulink model of brushless dc motor for electric vehicle for regeneration.

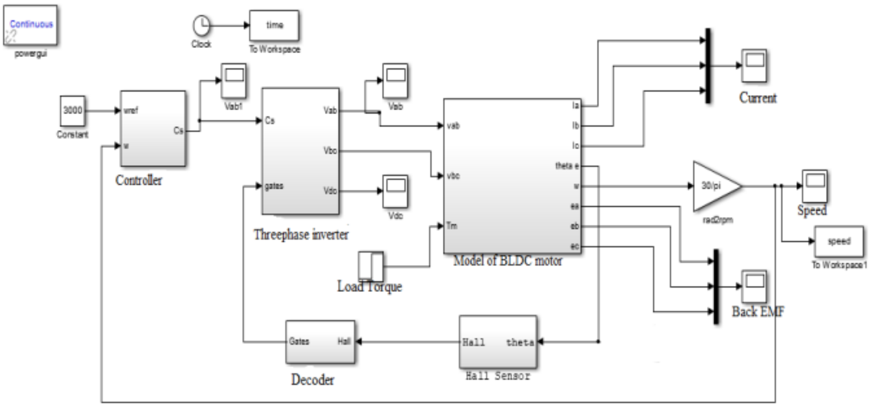

Fig.9 .MATLAB/Simulink model of BLDC motor electric vehicle

Figure 10 shows the speed characteristic of brushless direct current motor. Simulation results show that the speed of the motor is obtained 3000 rpm which is the speed rating of the desired system.

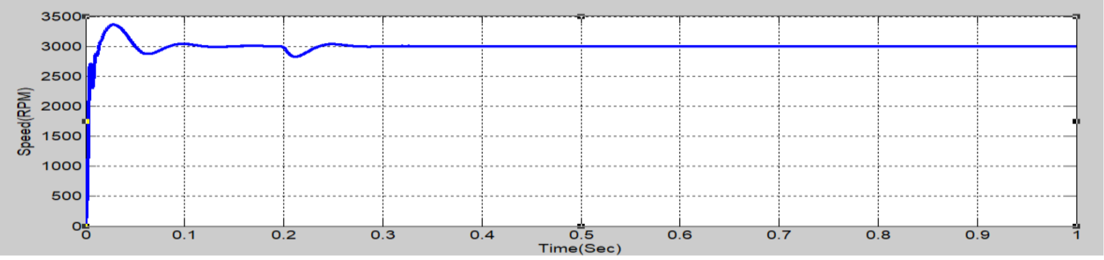

Fig. 10.Simulated speed curve of brushless dc motor for electric vehicle

Figure 11 shows the simulated current curve, the current rating according to the design parameter is 33 A.

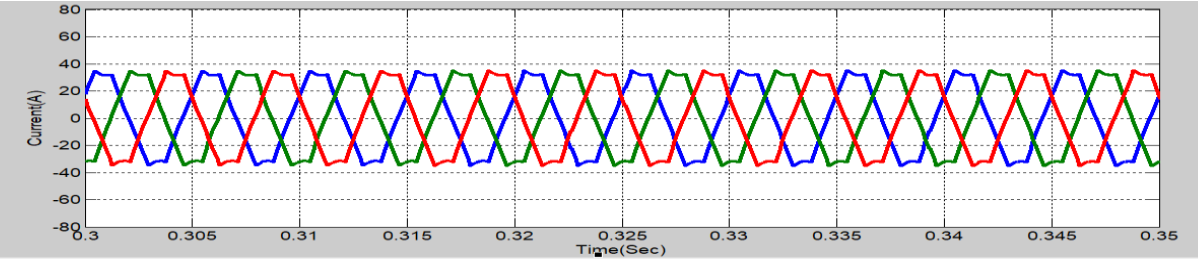

Fig. 11.Simulated current curve of brushless dc motor for electric vehicle

Figure 12 shows the torque curve of the brushless dc motor according to the design it is 5.2 A. The simulated torque is 4 A.

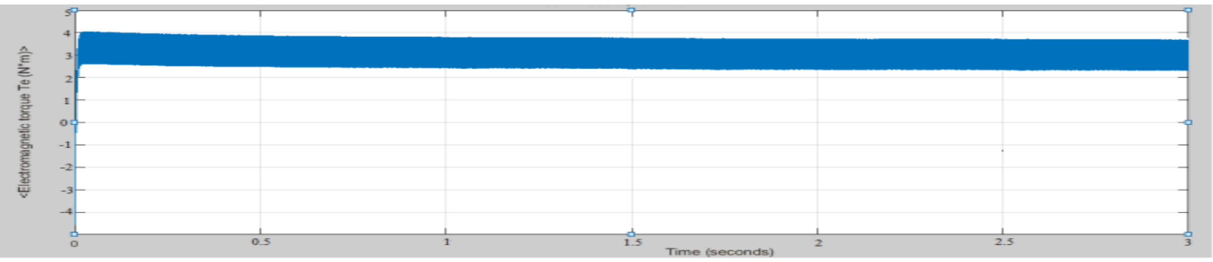

Fig. 12.Simulated current curve of brushless dc motor for electric vehicle

Figure 13 shows the MATLAB/Simulink model when brake is applied.

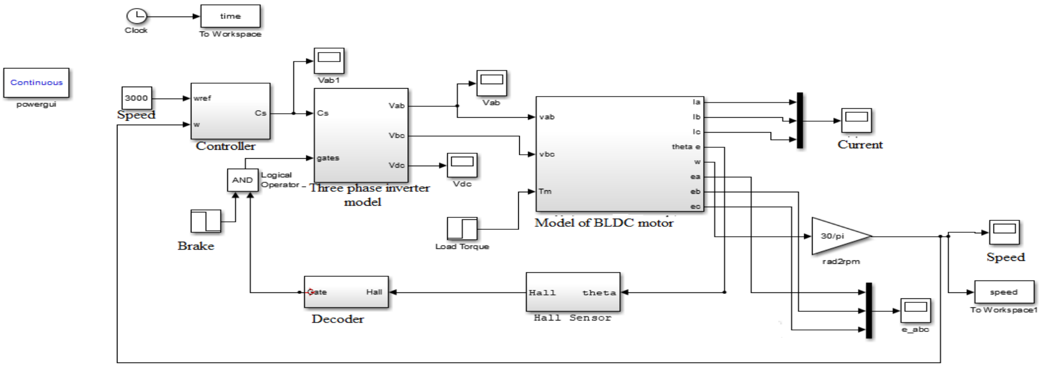

Fig. 13.MATLAB/Simulink model of BLDC motor when brake is applied

Figure 14 shows the simulation result of brushless dc motor when brake is applied.

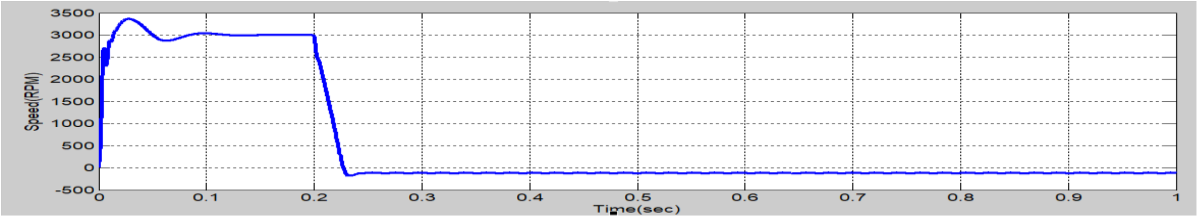

Fig. 14.Simulation of BLDC motor when brake is applied

Figure 15 shows the MATLAB/Simulink model of proposed system for regenerative braking

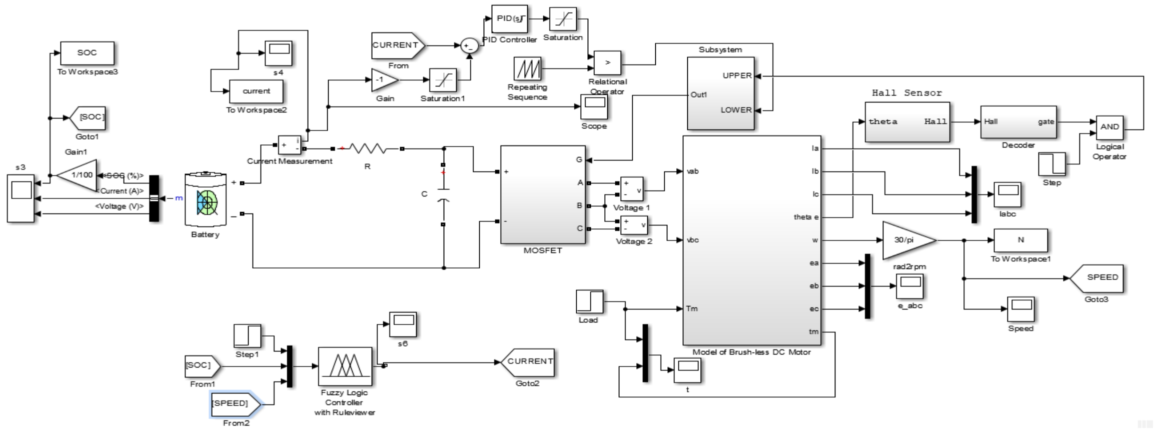

Fig. 15.MATLAB/Simulink model of BLDC motor for proposed system

Figure 16 shows the simulation result of battery state of charge (SOC) when brake is applied. The battery state of charge gradually reduced when the vehicle is running, and after the time 2sec a brake is applied at that time the SOC increases.

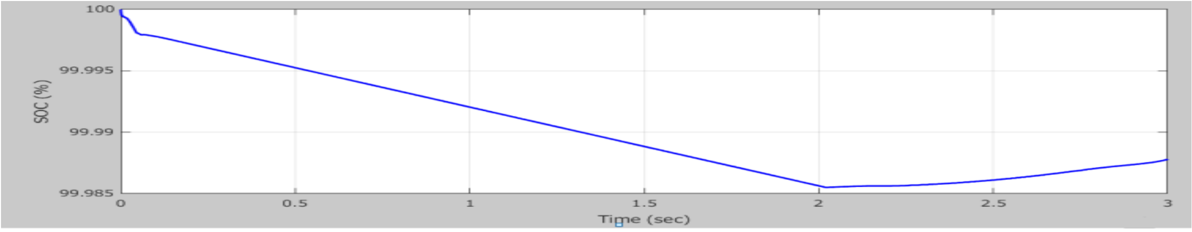

Fig. 16.Simulation result of battery state of charge

Figure 17 shows the torque curve when brake applied at 2 sec the torque become negative.

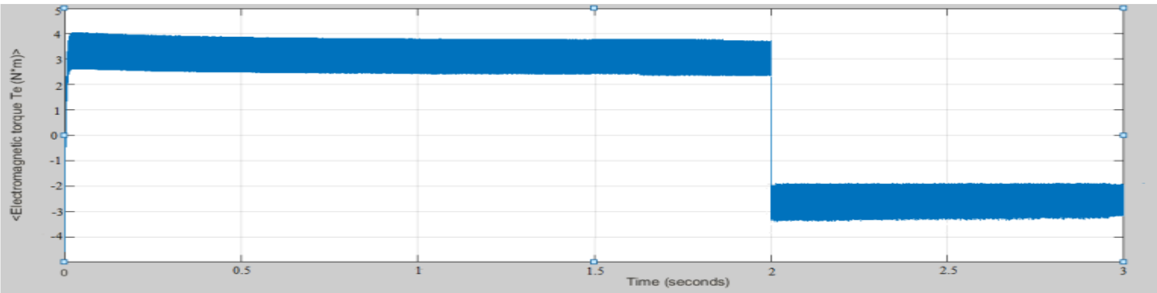

Fig. 17.Simulation result of battery state of charge

VI. CONCLUSION

Utilizing regenerative braking of electric vehicle can reduce the energy consumption to an extent which reduces the environmental pollution and reuse the wasted energy proper switching schemes. It increases the driving range of electric vehicle. For the sudden braking of an electric vehicle instantaneous power is very high in-order to store this huge amount of power for a short time, high power density storage source is needed super capacitor is used here. By combining a high energy density source to a high power density source can get the advantage of both sources. HESS using battery and super-capacitor are proposed also nonlinear control techniques will implement for the effective utilization of regenerative braking energy.

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