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Engineering

REGENERATIVE BRAKING SYSTEM FOR ELECTRIC VEHICLE WITH BLDC MOTOR

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ABSTRACT Increasing trends of electric vehicles based on utilization of hybrid energy storage system (HESS) driven by BLDC motor is gaining wide over attention. Here, a new regenerative braking system (RBS) is proposed with HESS topology to drive BLDC motor, which offers advantages such as efficient regenerative braking, battery safety and improved vehicle acceleration. The HESS is composed of a supercapacitor module, battery pack, buck converter and diode. During regenerative braking, the BLDC acts as a generator and kinetic energy of the vehicle is harvested by the supercapacitor using appropriate switching template of the inverter. The harvested energy can be utilized to improve the vehicle acceleration and keep the battery pack from deep discharging during driving uphill. The fuzzy logic controller (FLC) is used for braking force distribution and the result is demonstrated using MATLAB Simulink.

KEYWORDS : Hybrid Energy Storage System (HESS), Regenerative Braking System (RBS), Fuzzy Logic Controller (FLC).

INTRODUCTION

Electric vehicles (EV) are gaining increasing attention for having unique features such as low emission, high efficiency, and quiet operation. Complementary features of batteries and supercapacitors can be effectively used in a Hybrid Energy Storage System (HESS). Most EVs are driven with the help of energy stored in a battery. But the fundamental challenges for commercialization of EV are reduced driving extent and battery charging time. Effective battery usage and advanced motor control have turned into an important consideration in EVs. Chemical

batteries have been in use for quite some time, as the main energy storage system in many industrial applications. They are currently the dominant technology in the electric car industry. To use the battery's energy productively is a prime challenge in EVs. The batteries have few shortcomings such as limited life-cycle, limited power density as well as high cost.

In the proposed topology, supercapacitor voltage is taken higher compared to lead acid battery. The supercapacitors are electric double layer capacitors that offer many outstanding features like high power density, long life-cycle etc. Although the supercapacitor has many benefits supercapacitors can't be used as the only energy Storage System because of its relatively low energy density. The motors commonly used in EVs are Brushed DC motors, Induction motors, SRM and BLDC motors. Even though induction motors are reliable they suffer from problems like low power density and low efficiency. For Brushed DC motors the maintenance required is high. SRM motors have high power density and high efficiency, but have high acoustic noise and torque ripple [1].

During braking, inertia of the vehicle forces the motor into generator mode. The energy thus a back EMF is generated, it won't be sufficient to be stored to the battery directly. The regenerated energy has to be boosted, if we use an additional boost converter for this the cost, size and complexity of the whole system increases. An effective solution for this is to use the motor's own power converter switches and winding inductance.

HYBRID ENERGY STORAGE SYSTEM

The hybrid energy storage system composed of high voltage supercapacitor as well as lead acid battery. A lower voltage battery pack is connected directly to the DC- link, therefore DC link voltage is relatively constant. A unidirectional DC/DC buck converter is connected in between the battery pack and high voltage supercapacitor[2]. The battery pack is paralleled with the supercapacitor module through a diode. The hybrid energy storage system is utilized to supply the BLDC motor via the three phase inverter.

In normal mode, the battery pack is lonely used to supply the BLDC motor. During vehicle acceleration or driving uphill, the peak power demand is required, then supercapacitor module will assist the battery pack through buck converter. Since the voltage of supercapacitor module is higher than that of battery pack, the diode is usually reverse biased. By effectively utilizing the MOSFET's in three phase inverter as well as the motor inductances and adopting a suitable switching pattern, an equivalent boost circuit is formed. Therefore, during regenerative process, the DC link voltage is boosted and hence the diode is forward biased. This way the breaking energy can be efficiently harvested by the battery.

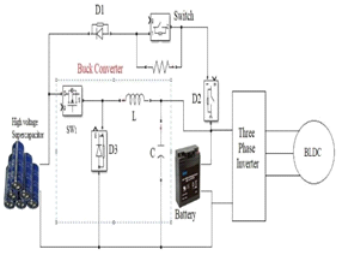


Fig 1: Circuit diagram of HESS

PROPOSED SYSTEM

The basic block diagram for the proposed system for regenerative braking of BLDC motor with battery-supercapacitor energy storage is shown in Fig 2.

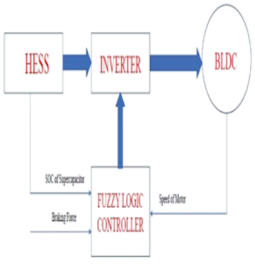


Fig 2: Block diagram of Proposed System

There are two modes of operation, normal mode and regenerative braking with battery and supercapacitor. HESS output is given as input to inverter, speed of BLDC motor is sensed and given as input to the FLC in addition to SOC of supercapacitor and breaking force.

Modes of Operation

Vehicle in normal mode

When motor power is less than / equal to battery power the vehicle remains in normal mode of operation. During normal mode the battery solely supplies the motor. The energy flow during normal mode of operation is given in Fig 3. In BLDC motor electronic commutation is

used to obtain the commutation sequence. The commutation sequence is obtained with the help of hall sensors by sensing the rotor position. The diode remains reverse biased during this mode of operation since the voltage of supercapacitor is higher than battery voltage and hence there is no effect of the rest of the elements in the circuit. The supercapacitor remains idle and the buck converter is in OFF state.

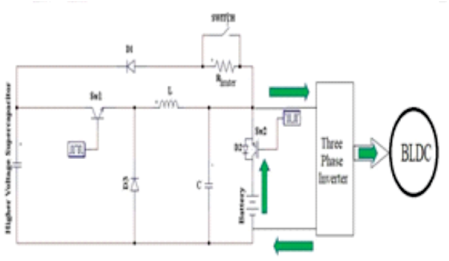


Fig 3: Circuit diagram of Vehicle at normal mode

Vehicle in Regenerative Braking mode

In Regenerative Braking mode the dc-link voltage will be boosted with the help of appropriate switching pulses to the lower switches of the inverter. So the diode D2 gets forward biased and the braking energy is harvested in the supercapacitor module. Instead of using an extra DC-DC converter, here boosting is accomplished by using the motor's own winding inductance and bidirectional switches of the inverter [4]. It reduces the components required and also the overall cost.

The working of the equivalent boost converter which is realized from the inverter has been discussed in the earlier section. The energy flow during regenerative braking mode of operation is shown in Fig 4.

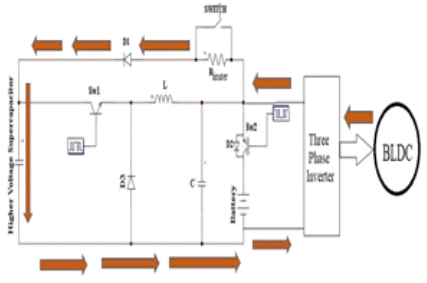


Fig 4: Circuit diagram of Vehicle at Regenerative mode

This mode of operation is activated whenever a brake is applied. When brake is applied the dc link voltage gets boosted and stores the regenerated energy to the supercapacitor, simultaneously the buck circuit is also turned ON. The Supercapacitor used is of high voltage, when compared to the battery voltage. The buck circuit is used to step down supercapacitor voltage to the battery voltage and charge the battery. Here the supercapacitor and battery are getting charged simultaneously, so whenever charge has to be stored to the supercapacitor it can be done. The energy is not directly stored to the battery on the grounds that if battery undergoes fast charging and discharging cycles frequently it affects the battery life.

Equivalent Boost Circuit

The working of the converter during regenerative braking can be described with the help of the circuit diagram given in Fig 5. A specific switching pattern is applied alone to the lower switches Q2, Q4 and Q6 of the inverter. The switches are then controlled via a high-frequency PWM signal [5].

When the upper switches are turned off, the diodes transfer current to the battery side. For easily regulating the regenerative voltage, single-switch modulation mode is adopted, where the active switch in the lower

side is supplied with PWM signals such any one switch in the lower leg is turned ON at a time.

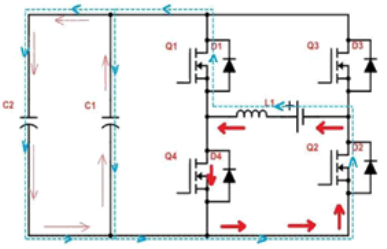


Fig 5: Equivalent Boost Circuit

FUZZY LOGIC CONTROLLER

In Fuzzy Logic Controller the inputs and outputs can be defined with the help of available member functions. Mamdani type FLC available in MATLAB Simulink is used here and model is shown in fig. Fuzzy rules can be written according to the load requirement. Here FLC is used for the braking force distribution between the front and rear wheels for a smooth and efficient braking. The braking force distribution depends on the braking force, SoC of supercapacitor, Speed of the motor etc. [3].

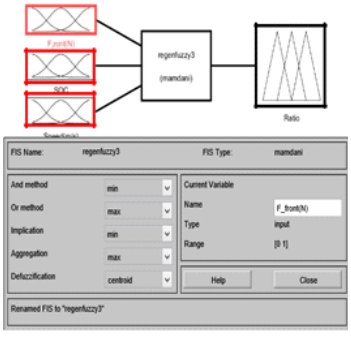


Fig 6: Fuzzy Logic Platform

The braking force values can represent the braking distance and required time by the driver. Large braking force means the vehicle has to be stopped immediately. During such situations the proportion of regenerative braking force has to be reduced. When braking force is middle, the ratio of regenerative braking force can be increased. Also for small braking force a large regenerative braking force can be applied so that maximum possible energy can be recycled.

When SoC is less than 10%, the internal resistance of the battery will be a high value and during this time it's not desirable to charge the battery; so regenerative braking force has to be small. When SoC is between 10% & 90% the battery can be charged, so regenerative braking force can be increased correspondingly. But when SoC is beyond 90% charging current has to be decreased to avert lithium ion deposit so regenerative braking force has to be decreased.

Vehicle speed is an important factor in braking safety. When speed is low regenerative braking force also should be low and for medium speed it can be increased to a proper value. For high speed, the regenerative braking force is set at the highest, so that maximum energy can be harvested.

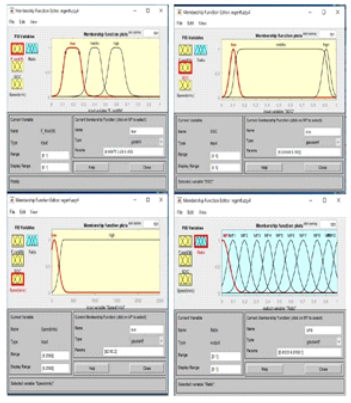


Fig 7: Member function Editor

Sl. No	Speed	SOC	Force	Regenerative Braking Force	Sl.No	Speed	SOC	Force	Regenerative Braking Force
1	High	High	Low	MF10	10	Low	High	Low	MF3
2			Medium	MF3	11			Medium	MF3
3			High	MF1	12			High	MF2
4		Medium	Low	MF10	13		Medium	Low	MF1
5			Medium	MF7	14			Medium	MF4
6			High	MF2	15			High	MF5
7		Low	Low	MF5	16		Low	Low	MF3
8			Medium	MF4	17			Medium	MF5
9			High	MF4	18			High	MF5

Fig 8: Fuzzy Rules

SIMULATION WORKS

The simulation of the proposed system was done in MATLAB Simulink. The simulation diagram for the proposed system is shown in Fig 9. Here a BLDC motor was driven by using an inverter by sensing rotor position from the hall sensors & these signals are converted to pulses by using appropriate logic. Initially the gate pulses are given from the hall sensor signals, after a certain simulation time brake is been applied.

The output of fuzzy logic controller is given as reference to the PI controller. The reference and the current towards supercapacitor is compared to get the error signal. The error is given to a PI controller and its output goes to a saturation block. The output of saturation block & repeating sequence is given to a relational operator and thus pulses are generated. As the braking force varies, the pulse width of the signal also varies thus controlling the boosting operation during braking.

The switching pulse for the switch in the buck converter is given using a PI controller. The current flowing towards the battery is compared with a reference value and the error is given to a PI controller. Its output goes to a saturation block and the output of saturation block and repeating sequence is given to a relational operator. Thus pulses are generated.

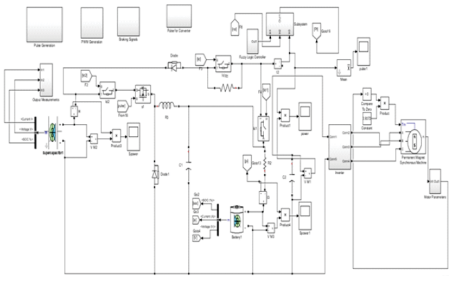


Fig 9: Simulation Model

SIMULATION RESULTS

The simulation results obtained by simulating the regenerative braking of a BLDC motor are discussed below. The waveform for motor speed is shown in Fig 10. An initial speed is set in the motor parameters, so that the simulation time required to reach the rated speed can be reduced. During normal mode the speed remains nearly constant and after braking speed starts reducing.

The supercapacitor parameters are shown in Fig 12. From the supercapacitor voltage, current & SoC waveforms, it can be inferred that till brake is applied, i.e, up to 15s simulation time the supercapacitor current is zero whereas the voltage & SoC remains constant. During regenerative braking mode the voltage and SoC increases and also current is negative which indicates the charging of supercapacitor.

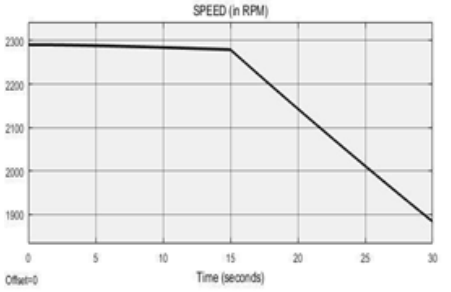


Fig 10: Motor Speed

The battery current, voltage & SoC are given in Fig 11 respectively. From the waveform of battery parameters it can be seen that in normal mode of operation the a steady current is drawn from the battery while the SoC & voltage of the battery reduces and during regenerative braking mode the battery voltage increases along with a slight increase in SoC which is not visible in the Fig 11 and current is negative (nearly 0.2A), which denotes the charging current of battery.

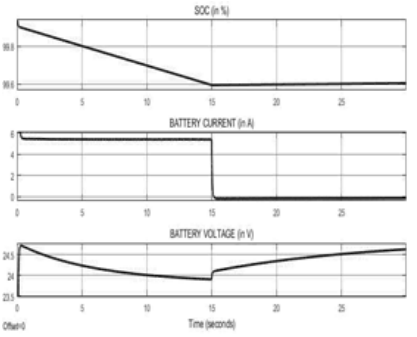


Fig 11: Battery Characteristics

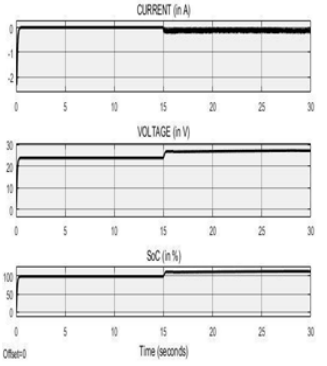


Fig 12: Supercapacitor Characteristics

The power of the motor used here is 60W and from waveform given in Fig 13, it can be observed that nearly one-third of power is obtained back during regeneration.

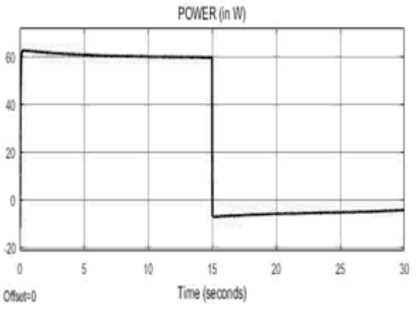


Fig 13: Motor Power

EXPERIMENTAL SETUP

The experimental setup for inverter section is shown in fig 14.

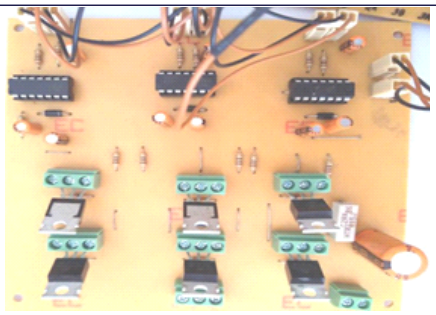


Fig 14: Inverter Section

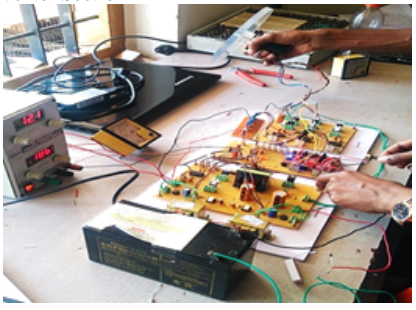
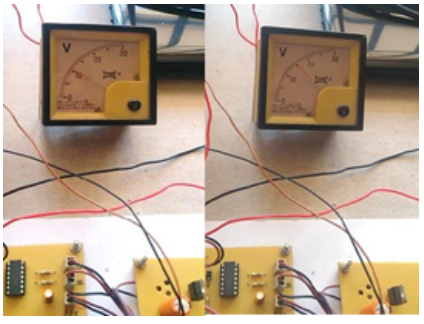


Fig 15: Experimental setup to check transfer of energy to superc apacitor



(a) **(b)**

Fig 16 (a) Supercapacitor voltage under normal mode
(b)Supercapacitor voltage when brake is applied

TABLE – 1 DETAILS OF BLDC MOTOR

Parameters	Specification
Voltage	24 V
Continuous Current	2.18 A
Output Power	52.5 W
Speed	4000 rpm
Rated Torque	1.25 kg-cm
No. of Poles	8

The Fig 16 (a) shows the supercapacitor voltage under normal running condition, which is around 12V and Fig 16 (b) shows the supercapacitor voltage when brake is applied, the voltmeter reads nearly 17V. From these readings it can be clearly seen that supercapacitor is getting charged

CONCLUSION

Regenerative Braking helps to earn some extra driving miles in an EV, by exploiting the generator operation of motor and boost operation of motor driver inverter. A simulation for the prototype of Regenerative Braking System of an EV with supercapacitor-battery energy storage has been done in MATLAB Simulink. To attain smooth and reliable braking force distribution Fuzzy logic controller is used and a PI controller is used for controlling the braking current. Hardware for the prototype was implemented and regeneration of BLDC motor was accomplished with the help of flywheel, as the kinetic energy storage device. The regenerated energy was transferred to the supercapacitor.

REFERENCES

[1] O.C.Kivanc, O.Ustun, G.Tosun and R.N.Tuncay, "On Regenerative Braking Capability of BLDC Motor", Industrial Electronics Society, IECON 2016 - 42nd Annual Conference of the IEEE, pp. 1710-1715, December 2016.

[2] Farshid Naseri, Ebrahim Farah and Teymoor Ghanbari, "An Efficient Regenerative Braking System Based on Battery/Supercapacitor for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles with BLDC Motor", IEEE Transactions On Vehicular Technology, Vol. 66, No. 5, pp. 3724-3738, May 2017.

[3] Akhila M and Prof. Ratnan P, "Brushless DC Motor Drive with Regenerative Braking using Adaptive Neuro based Fuzzy Inference System", International Conference on Electrical, Electronics, and Optimization Techniques, pp. 748-751,2016.

[4] Xiaohong Nian, Fei Peng, and Hanng Zhang, "Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor", IEEE Transactions on Industrial Electronics Vol. 61, No. 10, p, p.5798-5807, October 2014.

[5] Xu Jiaqun and Cui Haotian, "Regenerative Brake of Brushless DC Motor for Light Electric Vehicle", 18th International Conference on Electrical Machines and Systems, pp.1423-1428, October 2015.

[6] A. Khaligh, and Z. Li, "Battery, ultracapacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in hybrid electric vehicles: State of the art," IEEE Trans. Veh. Technol., vol. 59, no. 6, pp. 2806-2814, April 2010.