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Bi-Directional Regenerative Braking and Regenerative Braking using Ultra – Capacitors

Ishtiaq Ahmed R[1] | Prof Vijaya Krishna M[2] | Dr Sharana Reddy[2]

[1]PG Scholar, Electrical and Electronics Engineering, Ballari Institute of Technology and Management, Ballari, Karnataka, India
[2]Professor, Electrical and Electronics Engineering, Ballari Institute of Technology and Management, Ballari, Karnataka, India

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ABSTRACT

In this paper, factors affecting the energy stored in the batteries of an electric vehicles's. Theenergy used while applying the brake is lost in the form of heat the kinetic energy of braking canbe reused for the purpose generating power and charging the battery /Ultra- Capacitors as abackup, the system has been developed using MATLAB Simulink. Simulation performance of theBLDC Motor and its control for regenerating the power back to main source. Also developed theUltra-Capacitors modelling for charging and discharging.

KEYWORDS: BOOST CONVERTER, Voltage Source Inverter, Ultra-Capacitors, BLDC Motor Controller using MATLAB/Simulink.

INTRODUCTION

In recent years, increasing the demand for of anelectric vehicle transport system is critical toachieving energy for saving, and also greenhousegas (GHG) emission will be reduced. In general,electric vehicle operations can be categories intofour different modes of acceleration, sailing,drifting, and braking. During the acceleratingmode, the vehicle accelerating and drawing energyfrom an electrical vehicle operation. In the sailingmode, the power of the motor is nearly constant. Inthe braking mode, the operation of vehicledecelerates until it stops. Bi-directional converteris also known as energy management converter. Inelectric vehicle the bi-directional DC-DC converteris used for capturing kinetic energy of the motorwheels and used for charging of ultra-capacitorsduring regenerative braking by reverse flow ofenergy from heat to electrical energy. By using this energy from heat to electrical energy. By using thisconverter for powerconditioning and smooth flowof power to the wheels of electric vehicle.

In many industries the bi-directional convertersare used for different applications because of hisswitching operation at high frequency as DAB(Dual active bride) and IBDC (isolated bidirectionaldc-dc converter) both of the convertershaving galvanic isolation, and storage of surplusenergy and efficient for flow of power withoutwasting of energy.A conventional buck-boost converter manages topower flow in one direction only, but the power canflow in both the direction known as bi-directional.Bi-directional converters are the devices used forstep down or step up the voltage levels with thecapability of flow power in either directions or inbackward direction. Bi-directional converters areused to work as a regulator of power flow of the DCbus voltage in both directions.

A conventional dc-dc converter can be convertedinto Bi-directional converter using bi-directionalswitch by using diode in anti-parallel with IGBT orMOSFET switching devices allowing current flow in

both the directions using switching operation of thedevices. There is an over-voltage limit to protectequipment in the transit system. To adhere this asa limit, a braking may not be able to inject itsregenerative energy into the battery. The excessenergy dissipated in the form of heat to overcomethis on board or wayside damping resistors areused.

The main aim of this thesis is to provide acomprehensive review of the research efforts,studies, and implementations that have beenpresented by both academia and the industry onmaximizing the reuse of regenerative brakingenergy. Various types of solutions and technologieshas been described and also discussed. Theadvantages and disadvantages of each solutionhave been presented.

STRUCTURE OF PAPER

The paper is organized as follows: In Section 1, the introduction of the paper is provided along with the structure, important terms, objectives andoverall description. In Section 2 we discuss related work. In Section 3 we have the complete information about Modelling of Hev system. Section 4 shares information about the simulation model templating system created for it, its advantages and disadvantages. Section 5tells us about the methodology and the process description. Section 6 tells us about concludes the paper with references.

OBJECTIVES

1. To analyze and study factors that are responsible for regenerating the voltage
2. To develop a mathematical model ofregenerative braking and study the outputobtained from the mathematical model
3. To develop a stimulating model of the project using MATLAB/SIMULINK for the various speed of the motor operation in forward and reverse mode.
4. To analyze the simulation results and suggest a possible solution

LITERATURE REVIEW

There are numerous works that have been done related HEV system modelling and algorithms.

MD. Yaseen[1] proposed the system "Abidirectional DC to DC converter (BDC)" ispresented interface for the main source (HVS),auxiliary source (LVS), and a DC-Bus with variouslevels of voltage which are made in Hybrid ElectricVehicle (HEV). The circuit operates on the principleand modes of operation of bi-directional dc to dcconverter which were discussed and Simulationwaveforms of Dual Source Low Voltage PoweringMode, DC Bus High Voltage Regenerating Mode,Dual-Source High Voltage Boost/Buck Mode, andthe comparison between PI and ANN aredemonstrated that it can be successfullyimplemented for the hybrid electric vehicle.

Joseph Godfrey [2], V. Sankaranarayanan "A novel electric braking" Methods that is based on the brake pedal depression is proposed in this paper. Many previous braking Simulation results for the proposed braking system for the duty cycle of 0.7. Experimental result for the given braking system for 0.3 duty cycle. And the methods used such as single, two, three switch topologies and plugging are together to achieve the new braking strategy. There are two main parameters of HEV such as stopping time and energy regeneration are been taken to achieve at this represented scheme. As their performances are studied using both numerical simulation and experiments. It has been concluded that the regeneration is good for the single, three switch method, and stopping time is observed good for two switches and plugging.

HayatiMamur [3] and AlperKağanCandan proposed the system referred to as a "Simulation of Regenerative Braking of BLDC Motor for ElectricVehicles" within the study of this paper, asimulation of regenerative braking BLDC motor that utilized in EV's has been dispensed in MATLAB/Simulink. For the period of time from 4 seconds to 10 seconds fundamental quantity, the BLDC motor draws power from the battery. After 4 seconds, regenerative braking was applied to the BLDC motor.

However there has been little to no work put into the viability of image processing to achieve electronic automated invoicing.

MODELLING OF HEV SYSTEM

THERE ARE NUMEROUS IMAGE AND PDF PROCESSING LIBRARIES THAT WE CAN USE TO EXTRACT THE RAW TEXT OF OUR INVOICE FROM. WE WILL DISCUSS PDFTOTEXT, TESSERACT AND TESSERACT4.

*A.**Equivalent circuit of inverter:***

Inverters are of stationary power device whichproduces a Alternating current (AC) output asDirect Current (DC) input power supply. That areused in controllable AC power drives, shunt activepower filters, Uninterruptible Power Supplies(UPS), etc. For a sinusoidal AC outputs, thefrequency, magnitude, and the phase sequence-needed a control. If a DC input given to voltagesource, that inverter will be termed to VoltageSourcing Inverter (VSI). Analogies, to CurrentSourcing Inverter (CSI), when the circuit takingcurrent as input then the circuit termed to be currentsource inverter. The VSI having the aptitude forcontrolling the AC voltage, in case of CSI controls theSAC (1-phase AC) output current. Design of an idealVSI such, that load connected at the output thatmaintains the current in other phases, inverters thatare grouped into two types:1. 1-Phase Voltage Source Inverter (VSI)
2. 3-Phase Voltage Source Inverter (VSI)

Basic circuit of inverter:

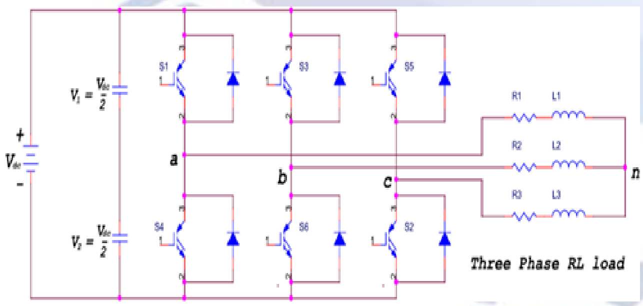

Figure:1 VSI connected to RL load

B.Proposed System for the Operation:

The input supply required as 690V, 50 Hz 1phAC. To obtain this input we have to use a Lowvoltage transformer of 100 Kva 240V/690V. Theblock diagram of BLDC motor in traction modeshown in the following figure 1. Energy injectedfrom the input source and supply to the load, the 1-phase four quadrant converter voltage and currentare the configuration of same sense, with theconverter to generate energy from the load's pointof view the proposed system during operatingmode is provided below:

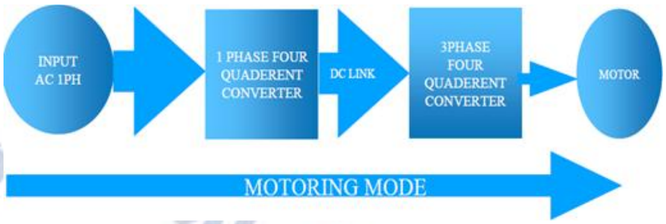

Figure 2 Block diagram of BLDC Motor in Motoring mode of operation

C. Regenerative braking mode PV photocurrent- -model

The BLDC motor in regenerating mode while, thevoltage and current are opposite to each other,energy comes back from the load, that is receivedby the converter and manages it, in receptor mode.And passes it in to the battery, for charging thesource and reuse the energy stored for thegeneratingpurpose and the cycle continues.

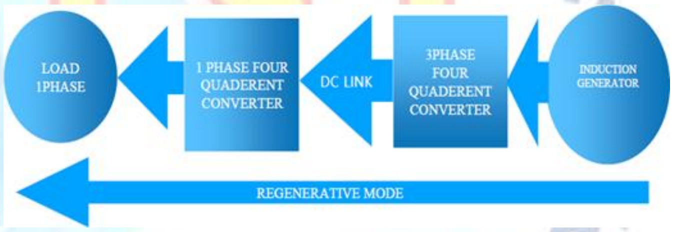

Figure 3 Block diagram of BLDC Motor inRegenerative mode of Operation

D. Four Quadrant Operation:

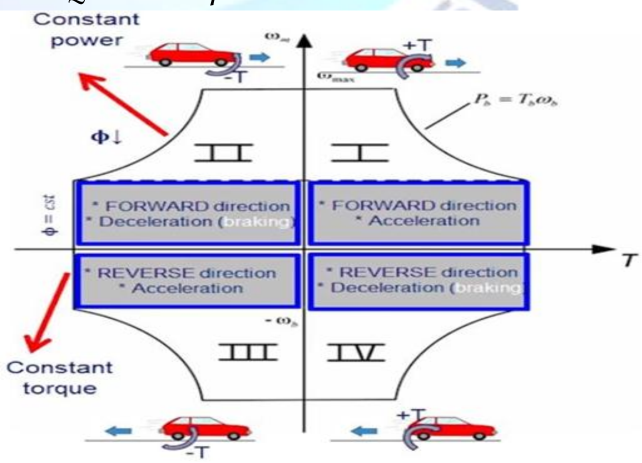

Figure 4 four quadrant operation proposed foroperation oh HEV

[ref EVS27 International Battery, Hybrid and Fuel Cell Electric VehicleSymposium]

In 1st quadrant the accelerating mode drivingthe wheels in forward direction called as motoringmode developing a mechanical power to drive thewheels in forward direction. In the 2nd quadrantoperation that is braking mode where the brake isapplied to the wheels and rotate the motor inreverse mode developing the electrical energyknown as braking mode.
In 3rd quadrant operation the wheels rotating inreverse direction developing negative torque andgenerating power in positive and drive wheels inreverse direction known as reverse motoring mode.

In 4th quadrant Operation the brake in appliedwhile the wheels stop and motor rotating in reversedirection developing electrical energy from reversedirection known as reverse braking mode.

E. Model of Electric Vehicle system (EV's):

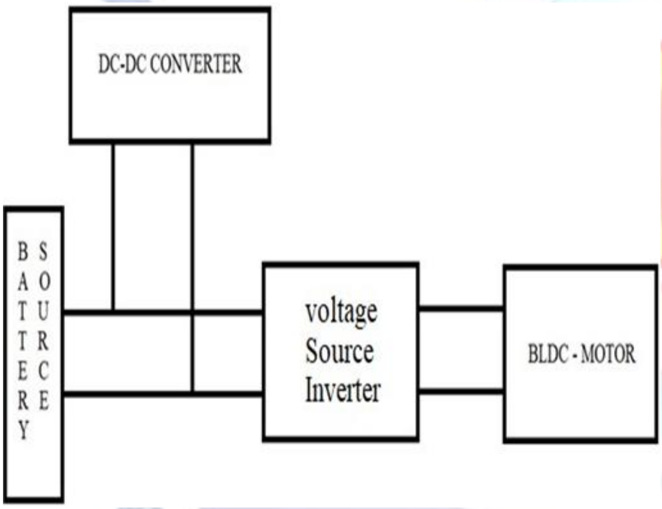

Figure 5 Electric vehicle base model

The proposed system of electric vehicle. WhereBLDC motor is fed from Boost converter via batterysource. The voltage from source to Boost convertergiven for the BLDC motor via VSI. The inductor isbeen placed at the output and voltage sensor isplaced to operate for control of DC voltage bycalculating its real voltage. The boost convertercontrol for the DC voltage that is indirectlyresulting in controlling BLDC motor speed. The useof the inverter is for electronic switching at lowerfrequencies, that helps in reducing the switchingheat loss in the inverter. The operations areanalyzed based on speeds, torque, and otheroperating conditions. An Ultra-Capacitor is addedwith a bi-directional DC-to-DC converter with extraenergy will be supplied during traction mode andmore energy will be retrieved from the motor duringbraking mode.

F. Boost Converter and operation modes:

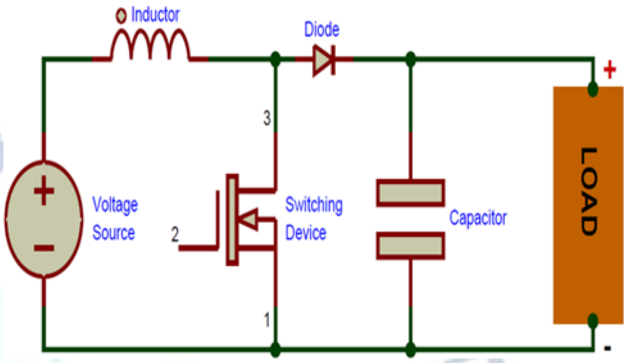

Figure 6 Boost converter circuit

[ref/components101.com/articles/boost-converterbasics-working-design]

The boost converter gives the load voltage morethan input voltage with the duty cycle of the gatepulses given for power electronic device (switch).The converter having a diode, electronic device,inductor and a capacitor. Boost converteroperating in two modes, the circuit of boostconverter.

1Mode 1: The circuit operation of mode 1practically, the electronic device(switch)'S' is ONand the inductor starts to charge as current flowsin the inductor while turned 'ON'. The voltageequations given for inductor and load given as:

$$VL = Vin.. (1)$$

$$Vco = Vo\ldots(2)$$

2Mode 2: The circuit operation of mode 2 shownin Fig.5.2 for the power electronic device (switch)'S' is turned 'OFF' and the inductor startsdischarging as no current flow in inductor duringthis 'OFF' time period and adds up with inputvoltage to give a boosted voltage for the load.

$$Vo=Vin + VL\ldots (3)$$

G. *Design Procedure of Boost Converter:*

The boost converter implemented on considering theequations; The PWM of the gate pulse given to theelectronic device (switch) to boost converter and isgiven as:

$$D = Vo/Vdo{-}Vn \ldots..(4)$$

The inductor in the boost converter beencalculatedby the equation:

$$I = (Vin*V)/(\Delta Io*Fsw) \ldots.(5)$$

The inductor ripple current is measured fromequation given:

$$\Delta Il = 0.2 *Vo/V \ldots.(6)$$

The capacitance used in the boost converterbeen calculated as follows:

$$Co = \Delta Ioc/(8 *Fsw*\Delta Vo \ldots.(7)$$

The capacitor ripple voltage is given usingthe equation given:

$$Co = 2\%\ of V \ldots.(8)$$

H. Converter and Motor Controller:

The controller for brushless motorand boost voltage converter incorporates with 2other segments' one for boost converter to attainthe output voltage (DC) the other is to reach motorrated speed.

V*dc = kV w….(9)

The blunder voltage signal (VE) determined bycontrasting the reference DC-voltage ($V*dc$) with thereal yield voltage to get the DC interface (Vdc) as:

VE= V*dc- Vdc….(10)

The erroneous voltage 'VE 'which is output fromthe generator, is given (PI) controller, havingvoltage control 'VC' given as:

VC(k) =VC(k-1) + kP {VE(k) – VE (k-1)} + KiVE(k)..(11)

where 'kth' is a sampling indicates 'k' and 'Kp' &'Ki'are the yield a proportionality and complimentaryaction executed by the 'PI' controller. Boostconverter's MOSFET 'Q' transformed are producedtogether comparing output voltage 'VC' of highrecurrence saw-tooth signal 'MC' signal otherwisecalled as bearer signal.

i. {If $MC<VC$ then Q is 'ON'}

ii. {If $MC\geq VC$ then Q is 'OFF'}

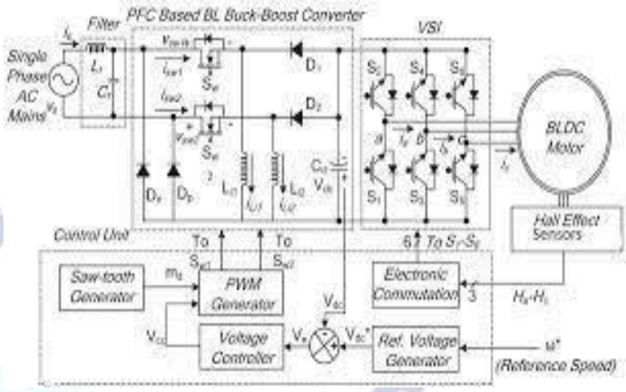

Figure 7 Control loop of the boost converter andBLDC motor

[ref IJAREEIE Vol. 6, Issue 12, December 2017)

When the current changes direction itchanges at the brushes as in brushed DC motors.Since BLDC's do not have brushes, switching isperformed by changing the appropriate phase of theinverter, which is called electronic switching.Toapply electronic switching to the BLDC motor,theVSI require a suitable exchangingarrangement,with an even current streaming for 3/2 from the VSI DC linker and kept evenly in the decent backtrapezoidal EMFs for the three stages. Photoniclobby impact positioning sensors are mounted at apoint of 60 degree.

At the point when the inverter switches S1,S2start to communicate the line current 'Iac' being tomove from the DC connected capacitor to themotor the measure of which is controlled by theinterface voltage (Ra and Rb) and the selfinductanceand cross-association hall sign of thestator winding should be decoded and sent by meansof reality, to get the appropriate changearrangements operate the motor in the samedirection.

I. Simulation Circuit and Desired Output:

In this, the motor runs in tractionmode from t=0 to t=0.8s and braking occurs att=0.8s. The battery will be discharged during thetraction mode along with the Ultra-capacitor (until%SOC>10%). And in braking mode, both will becharged. The battery will supply to the motorduring traction mode through the bi-directionalconverter (boost mode) and inverter. Duringbraking mode, the battery and Ultracapacitor getscharged through a rectifier and bi-directionalconverter (buck mode).

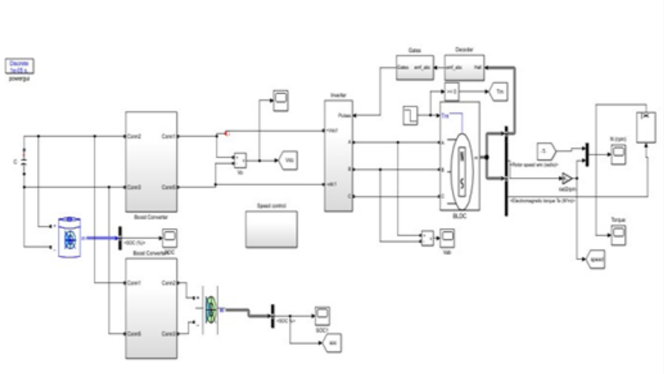

Figure 8 Simulation proposed for the regenerativebraking system

J. Simulation model of Boost-Converter:

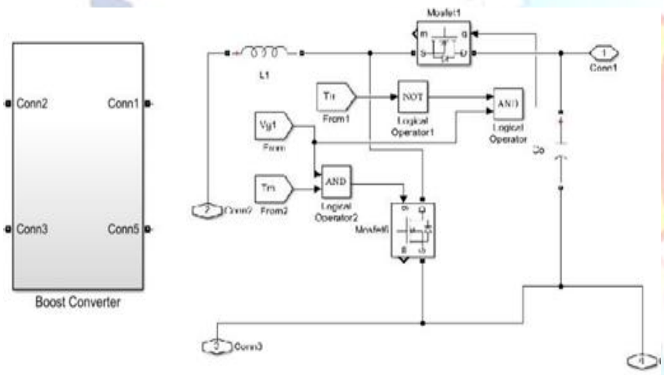

Figure 9 Simulation model of Boost-Converter

The block used in the simulation for theDC-to-DC boosting voltage converter input DCvoltage the booted DC output voltage. The DCsupply as an input that is given to the inductor as adevice that operates like a switch, and is placedacross the input. The secondary switch that to beused as a diode. The diode is been placed with thecapacitor, as the load they both have beenconnected in parallel with each other as shown inthe fig 9.a uninterrupted input current, and there by Boostconverter is being observed as constant inputcurrent. And the load that is seen as the constantvoltage source. The switching diode is turned ‘ON’and ‘OFF’ by using the technique called PulseWidth Modulation (PWM).

K. Simulation model of voltage source inverter:

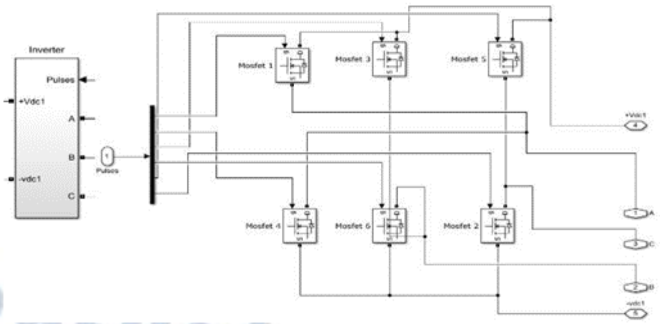

Figure 10 Simulation circuit of Voltage source inverter

The VSI are widely used for changing DC voltageto AC voltage the MOSFETs are been used asswitches for getting three-phase output pulses toproduce and drive the BLDC motor for theoperations and the logic used for the controlledSwitching of the MOSFET.

*L.*Logic operator and truth table for BLDC Motor:

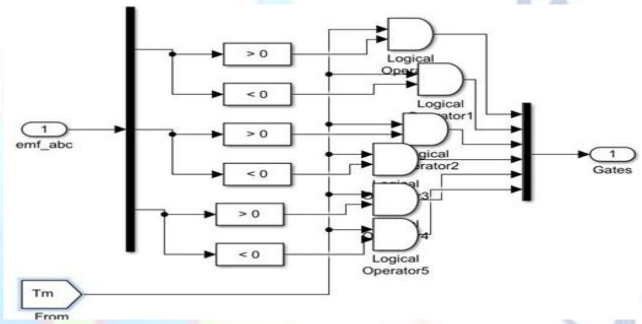

Figure 11 Logic Operation for BLDC Motor

In this, the %SOC reduces initially and as it reaches10% which is set as the minimum limit, it getsdisconnected after t=0.8s, the %SOC gets recoveredas the ultra-capacitor gets charged along with abattery.

RESULTS AND DISCUSSION

❖ Output from the boost-Converter:

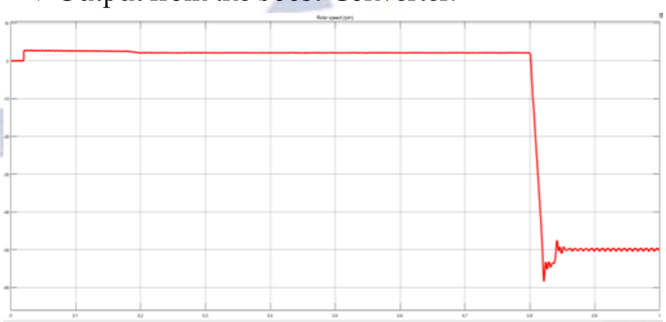

Figure 12 The DC voltage output of the boost Converter

In this graph representation, the dc voltage isaround 300V during traction mode and duringbraking mode, Curve shown in the graph is thevoltage getting bucked from 300v to 48v to keep thevoltage balanced in the system that the operating
switches shouldn't get damaged.

❖ Output obtained while Regenerating:

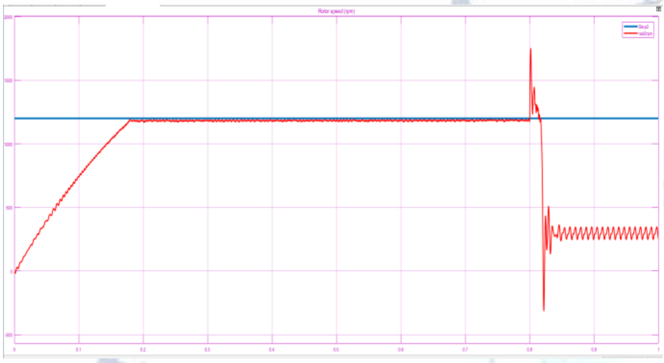

Figure 13 The motor speed reaches the reference speed at t=0.18s

During regenerative braking the speed of the motoris being reduced to a minimum value to charge thebattery and Ultra-Capacitors, the graph showingthe speed reduces below 25% of reference speed thebrake is applied to the system.
The disturbance isshown after the brake is applied as the motor speedgets reduced.

❖ Output obtained from the Ultra-capacitor:

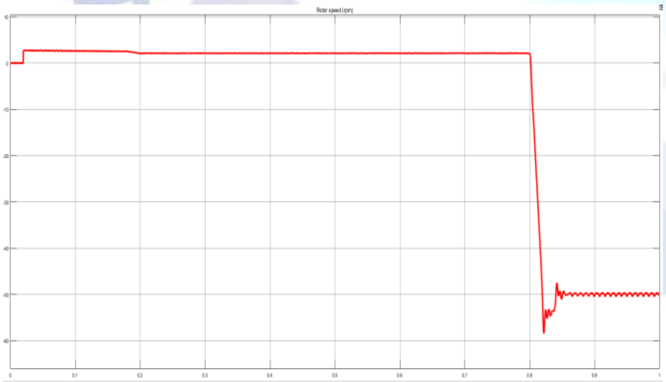

Figure 14 The motor speed reaches the reference speed at t=0.18s

During regenerative braking the speed of the motor is being reduced to a minimum value to charge the battery and Ultra-Capacitors, the graph showing thespeed reduces below 25% of reference speed afterthe brake is applied to the system. The disturbanceis shown after the brake is applied as the motorspeed gets reduced and the motor acts as likegenerator and starts regenerating the voltage backto the source.

❖ %SOC of Ultra-Capacitor:

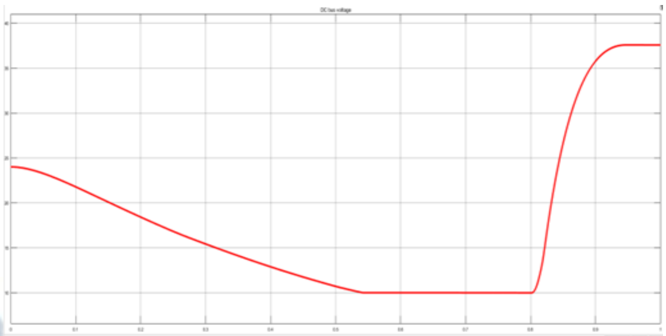

Figure 15 The %SOC of the Ultra-Capacitors

The operation of the BLDC motor from thefollowing table represents the flow direction ofcurrent direction from the switching device(MOSFET's) with hall sensor in order to set theposition of the motor. The truth table is as followsin Table 1:

CONCLUSION

The proposed system shows the storing of theelectrochemical energy in the Ultracapacitor whenthe brakes are applied to the vehicle an enormousamount of heat is generated and converted intochemical energy to regenerate the energy and storeit into the battery and in the Ultra-capacitor thatcan be used to drive the vehicle.Regenerative braking system neededdevelopment and for further more research to comeup with a systemthat holds much energy and stopsfaster. The timegoes on, designers, engineers andresearchers will be able to design absoluteregenerative braking systems, so these types ofmethods will be morecommonly used.
All the vehicles if in motion can benefited fromthis system by regenerating, energy that is lostduringthe braking technique. In Furthertechnologies the regenerative brakes be included innew system of motors that are more than efficient,whiledesigning 'HEV' regenerative braking system,andelectric systems which will be of liability toenergylosses. This type of braking system can beused inany hybrid vehicle as it can improve theefficiency of the vehicle and will reducing the use offossilfuels.
It increases the electric vehicle's fueleconomy It allows the conventional braking forfriction.Extra controlling components is necessary tomanage the regeneration. Maintenance cost is highfor protecting the components as well as the motorused Complexity depending upon control for theoperation of the regenerative braking

systemnecessary for the operation of the regenerativebraking system.

TABLE: 1 Truth Table for an BLDC drive with Hall Sensors

H_A	Hb	Hc	Va	Vb	Vc	Q_1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	+1	0	0	1	1	1	0
0	1	0	-1	+1	0	0	1	0	0	0	0
0	1	1	-1	0	+1	0	1	0	0	1	0
1	0	0	+1	0	-1	1	0	0	0	0	1
1	0	1	+1	-1	0	1	0	0	1	0	0
1	1	0	0	+1	-1	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0	0	0	0

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