Design, Implementation and Performance Evaluation of a Regenerative Braking System in Electrical Vehicles

Jagadisha N , Sanjay S ,Shilpashri V N , Dhanalxmi H R

Assistant Professor
Department of Electrical & Electronics Engineering
GSSSIETW Mysuru, Karnataka, India.

Abstract : In today's life Electrical energy becomes one of the basic needs. Electricity plays vital role in every human being's day to day life. Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. In present world energy crises is a major problem and the resources are depleting at a higher rate. Thus there is a need of specific technology that recovers the energy, which gets wasted usually. IC engines and hybrid energy vehicles are also the major source of the fuel consumptions. Generally in electrical vehicle whenever the brakes are applied the vehicle comes to a halt and the kinetic energy gets wasted due to friction in the form of heat. In order to use this dispersed energy in case electrical vehicle regenerative braking system can be employed. Use of regenerative braking system in automobiles enables us to recover most of the kinetic energy that is lost during the braking process.

In the present work investigation on basic design and components used in the regenerative braking for electric vehicles and model is designed / developed. The working mechanism was studied to understand how the Regenerative Braking System (RBS) could convert mechanical energy to electrical energy and also the implementation of the RBS with the help of MATLAB simulink. This simulation gives us a clear idea about the variation of various characteristics with time during the process of regenerative braking and also the exact amount of energy recovered.

The present project work can be implemented in all types of hybrid vehicles, Electric locomotives and airplanes at the time of applying break to reduce the speed of the vehicle as well as to generate energy.

***IndexTerms* - Regenerative Braking System (RBS), Electrical Vehicles, Simulink model.**

I. INTRODUCTION

In today's life Electrical energy becomes one of the basic needs. Electricity plays vital role in every human being's day to day life. Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy .In today's world energy crises is a major problem and the rate of depletion of the fossil fuels is increasing drastically day by day. Most of this fossil fuel is used as the input fuel for automobiles .In order to decrease the rate of consumption of the fossil fuels it is very necessary to largely reduce the intake of fossil fuels by automobiles .Thus, there is a need of specific technology that recovers the energy, which gets wasted usually .In order to use this dispersed energy in case electrical vehicle regenerative braking system can be employed. A brake is a device for applying a force against the friction of the road, slowing or stopping the motion of a machine or Vehicle [1]. In recent times, electric vehicles (EVs) have received much attention as an alternative to traditional vehicles powered by internal combustion engines running on non-renewable fossil fuels .An important fuel saving element in hybrid electric vehicles (HEV) is the regenerative braking system(RBS), saving a considerable amount of energy during the brake of a vehicle .Generally, in electrical vehicle whenever the brakes are applied the vehicle comes to a halt and the kinetic energy gets wasted due to friction in the form of heat. Use of regenerative braking system in automobiles enables us to recover most of the kinetic energy that is lost during the braking process.

The total energy dissipated through braking during a typical urban area drive may reach up to 34% of the total traction energy. In large cities, with frequent stops and lots of intersections, this portion may reach up to 80% [2]. During brake phase, the electric traction motor of an electric or hybrid electric vehicle can be easily controlled to function as a generator, converting some of the kinetic energy of the vehicle into electric energy. The recovered energy can be stored in an electric energy storage system and subsequently used for the propulsion, significantly reducing the vehicle's overall energy consumption and exhaust emissions.

The modeling of the electric vehicle has been done in MATLAB Simulink R2013a. The driver block makes a torque request which propagates through various power train components and realizes vehicle motion [4].System-level simulators have been modeled using empirical data that are based on measurements supplied by component manufacturers or extended from measurements obtained from literature sources. These are modeled in Simulink as Look-up tables. Other component models are physical or analytical in nature and are modeled using mathematical equations [5].

II. EXPERIMENTAL SETUP

The following circuit represents the circuit diagram of the hardware model. It consists of the following four major parts: Ease of Use

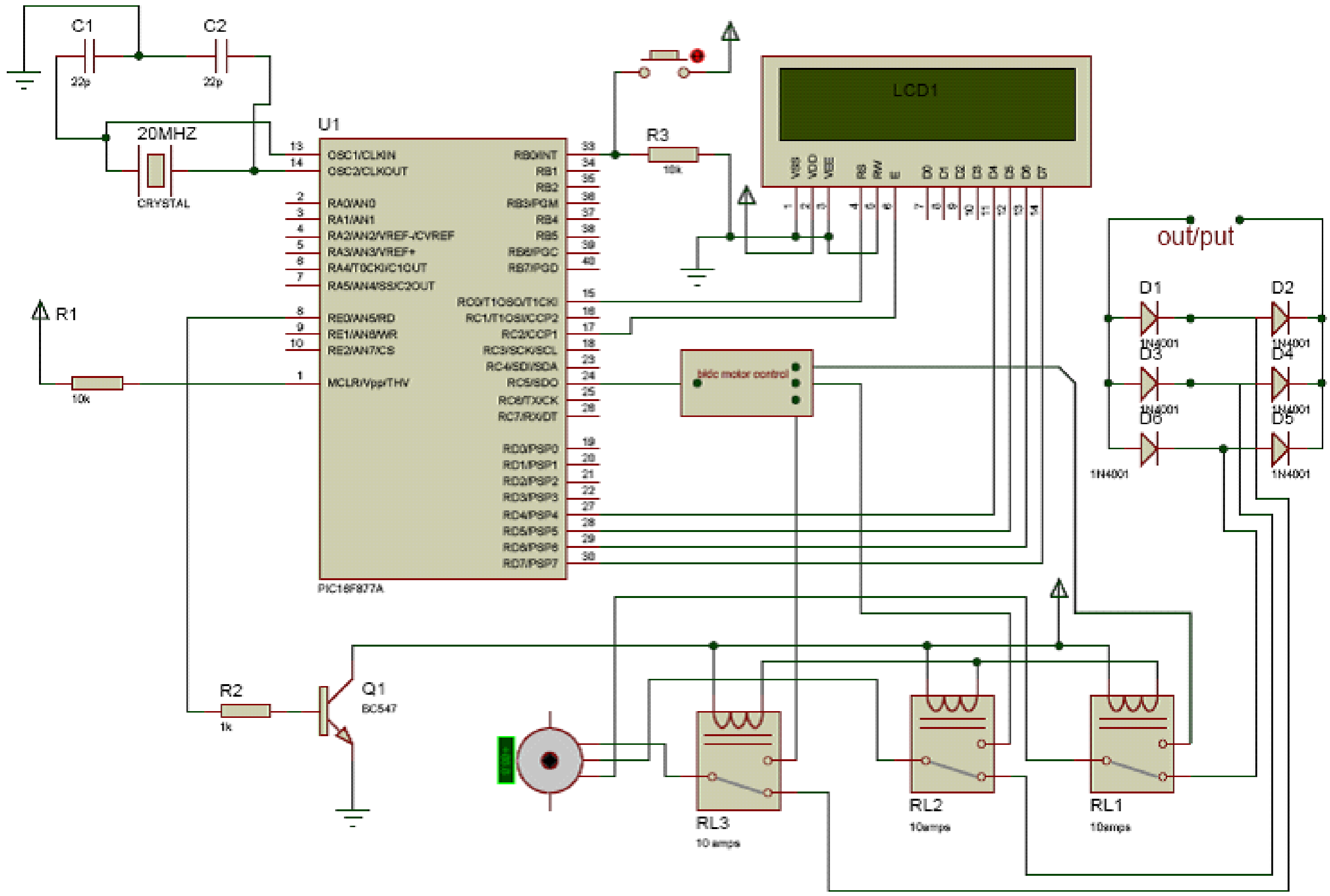

Fig. 1 circuit diagram of the hardware model

Microcontroller block (PIC16F77A):- This block accepts the input from the 12V DC battery, regulates it and this regulated output is further sent to the various components of the model.

BLDC Driver-Motor Block: - This block mainly consists of a BLDC Driver and BLDC Motor. The driver is used to control the speed and position of the rotor of the BLDC motor.

Relay block: - This block comprises of a set of relays, transistors and a freewheeling diode. It plays a major role during the changeover process from running mode to the braking mode.

Rectifier and storage block:-This consists of a 3 phase bridge rectifier, blocking diode and a 3V storage battery. During the process of regenerative braking the output from the motor is rectified and stored in the battery.

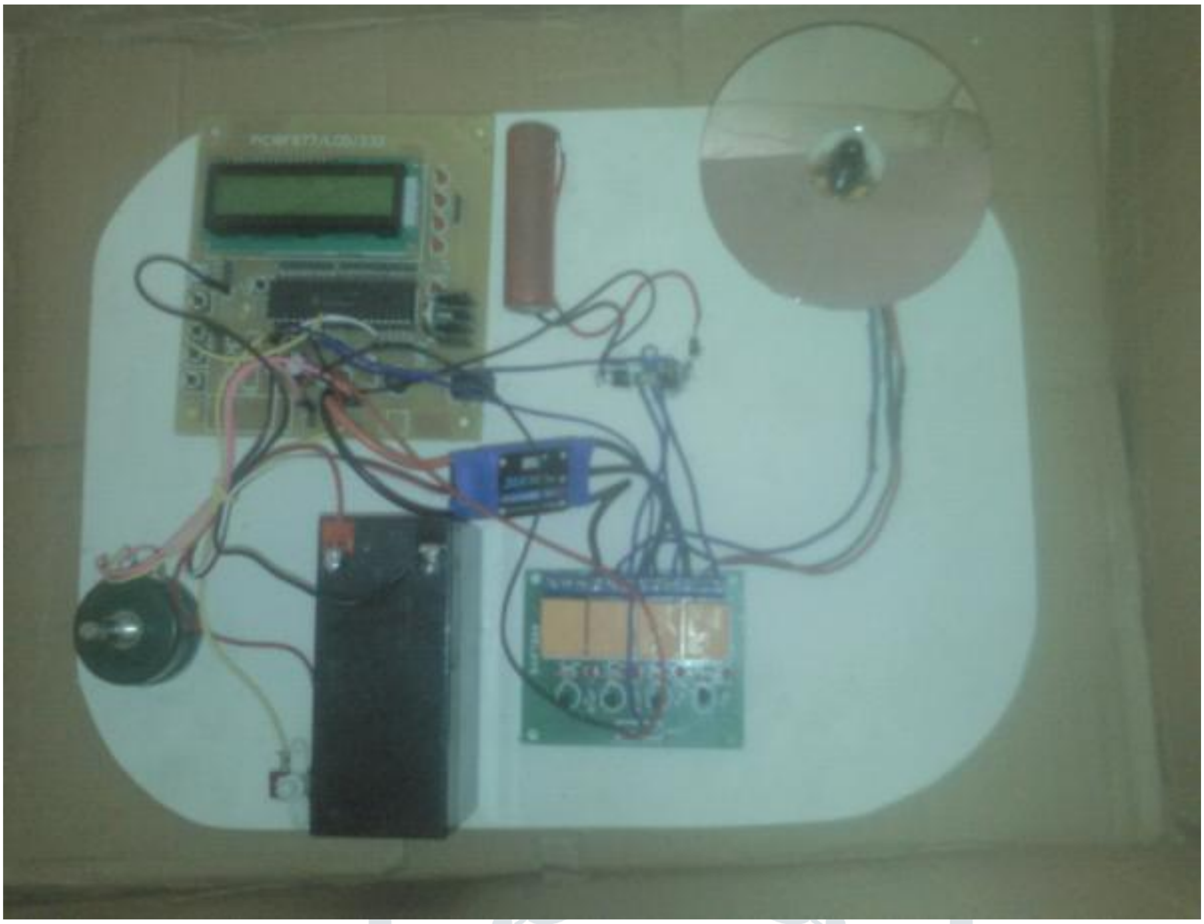

Fig.2 Hardware model of regenerative braking system

Fig 3 shows the simulation model for the regenerative braking system which contains the following main blocks

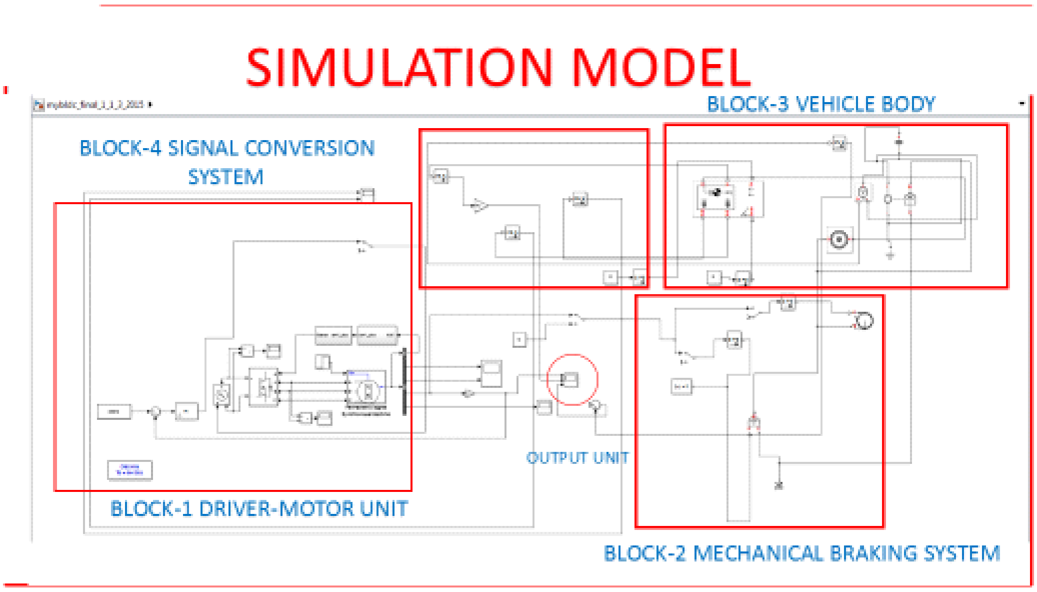

Fig 3 circuit diagram of the software model

The above circuit diagram can be divided into four main parts/blocks:-

Block-1 Driver-motor unit: This block consists of the following components:-

Input block : used to set the reference speed

PI Controller: Implements a controller with proportional and integral action.

Controlled Voltage Source: This block converts the Simulink input

signal into an equivalent voltage source.

BLDC Driver Circuit (Universal Bridge): The Universal Bridge BLDC Driver Circuit implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration.

BLDC Motor: The block operates in either generator or motor mode.

Firing angle truth tables: this table explains the series of operation of hall sensors as well as the power switches.

Voltage measurement block: used to measure the voltage.

Block-2 Mechanical braking system: This block consists of the following components:-

Band brake: The block represents a frictional brake with a flexible band that wraps around the periphery of a rotating drum to produce a braking action.

Ideal Angular Velocity Source: The Ideal Angular Velocity Source block represents an ideal source of angular velocity that generates velocity differential at its terminals proportional to the input physical signal.

Solver Configuration: The Solver Configuration block specifies the solver parameters that the model needs before to begin simulation.

Simulink-PS Converter: The Simulink-PS Converter block converts the input Simulink signal into a physical signal.

Block-3 Vehicle body: This block consists of the following components:

Vehicle body: The Vehicle Body block models a two-axle vehicle, with an equal number of equally sized wheels on each axle, moving forward or backward along its longitudinal axis.

Voltage sensor: it is a device that converts voltage measured between two points of an electrical circuit into a physical signal proportional to the voltage.

Rotational electromechanical converter: it provides an interface between the electrical and mechanical rotational domains.

Electrical reference: The Electrical Reference block represents an electrical ground.

Block-4 Signal conversion system: This block consists of the following components:-

PS-Simulink converter :converts input physical signal into the simulink signal

Gain element: The Gain block multiplies the input by a constant value (gain).

III. Results and Discussions

The amount of mechanical energy consumed by a vehicle when driving a pre-specified driving pattern mainly depends on three effects:

The aerodynamic friction losses

The rolling friction losses

The energy dissipated in the brakes

The elementary equation that describes the longitudinal dynamics of a road vehicle has the following form [6],

$Mv(dv(t)/dt)=F(t)-(Fa(t)+Fr(t)+Fg(t))$

where,

mv is the vehicle mass[kg],

v is the vehicle speed[m/s2],

Fa is the aerodynamic friction [in Newton],

Fr is the rolling friction [in Newton],

Fg is the force caused by gravity when driving on non-horizontal roads[in Newton]

The traction force Ft is the force generated by the prime mover minus the force that is used to accelerate the rotating parts inside the vehicle and minus all friction losses in the HEV [7].

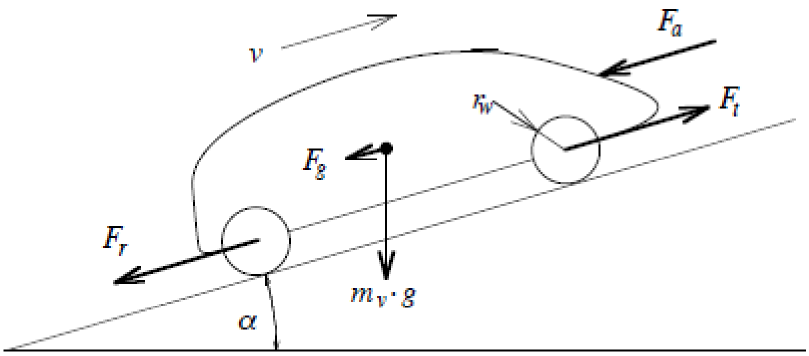

Fig.4 Schematic representation of the forces acting on a vehicle in motion.

The hardware model consists of a BLDC motor with driver circuit to convert electrical energy from source battery to kinetic energy. This motor is coupled with flywheel to drive the motor. When brakes are applied stored energy in flywheel is converted back into electrical energy. The variation of the values of voltage during Regenerative braking process is measured for various rotor speed which can be used to find out the output power generated.

Table 1: shows the voltage, current, and power recovered during braking process

Speed (rpm)	Braking		
	Voltage (volts)	Current (amps)	Power generated from motor(watts)
350	1.86	1.27	2.3622
430	1.96	1.8	3.528
550	1.98	2.4	4.752

Table 2: comparison of hardware and software output voltages

Speed in RPM	Hardware output voltage	Software output voltage
350	1.86	1.84
430	1.96	1.93
550	1.98	1.95

The following graph shows the comparison of speed of motor versus amount of voltage regenerated in hardware model and in simulation model.

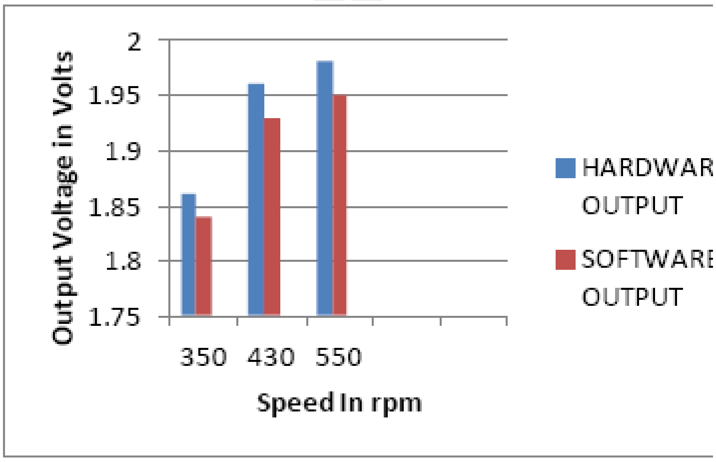

Fig 5: comparison of hardware and software output voltages

A similar regenerative braking model has been simulated with the help of MATLAB Simulink software. Here the real time analysis can be done by considering the vehicle body into consider and showing the variation of various parameter such as speed, voltage, current with respect to time.

Figure 5 shows the Combined output characteristic of Rotor speed (rpm),Vehicle speed(rpm),Voltage output(volts) with respect to time. Variation of the rotor speed , vehicle speed ,and output voltage during braking is shown below. When brakes are applied rotor speed decreases due to which the vehicle speed also decreases there by increasing the output voltage.

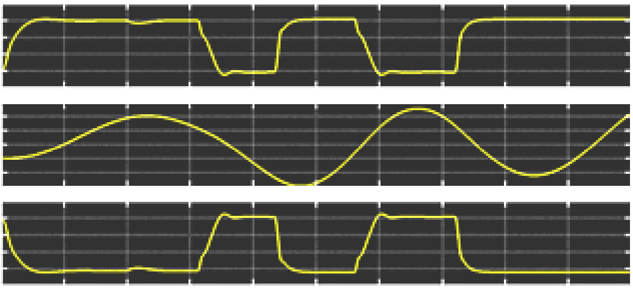

Fig.6 Combined output characteristic of Rotor speed(rpm),Vehicle speed(rpm),Voltage output(volts) with respect to time

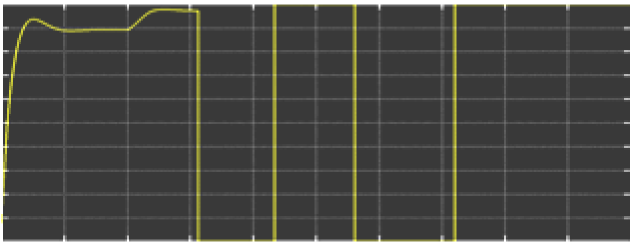

Fig. 7 DC Bus voltage during braking

Fig. 7 Variation of the DC Bus voltage during braking. When brakes are applied, the DC voltage drops to lower level

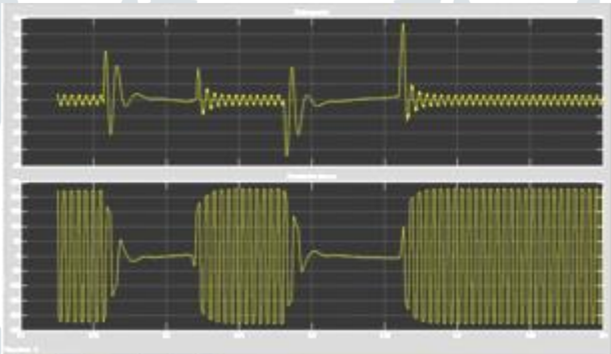

Fig.8 Stator current and Electromotive

Fig 7 shows the variation of the Stator current and Electromotive force with respect to the time during braking.

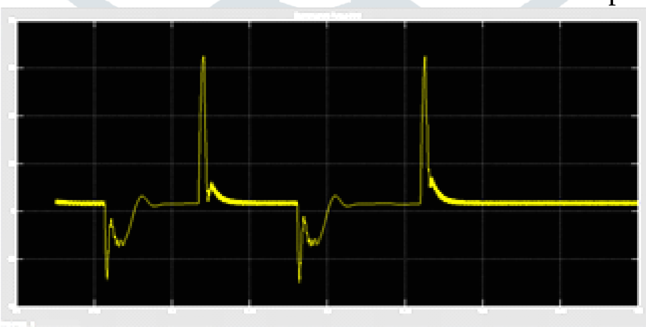

Fig 9 Electromagnetic torque force during braking

IV. Conclusion

The following conclusion can be drawn from the present project work,

The regenerative braking system used in the electrical vehicle satisfies the purpose of saving a part of the energy lost during braking. Also, it can be operated at higher temperature range and are efficient as compared to mechanical braking system.

The mechanical braking system stops significantly faster, but no energy is recovered and it is also causes wear and tear of the wheel and brake shoe.

The results from some of the test conducted show that around 30% of energy delivered can be recovered by the system.

Performance of the regenerative braking algorithm developed in this study is evaluated by the simulation. In the simulation dynamic model of the hybrid electrical vehicle power train is developed. In the modeling, motor, driver, tire, and other vehicle parts are obtained by modular approach using MATLAB simulink.

Regenerative braking system has a wide scope for future development and the energy savings. The use of more efficient systems could lead to huge savings in the economy of any country.

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