Regenerative Braking Using Super Capacitor in Electric Bike

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Abstract **– This paper proposes, a battery and super-capacitor combination of hybrid energy storage system (HESS) is proposed for braking of electric bike. A suitable dc to dc converter to interface between the super-capacitor and the battery/dc link to satisfy the real-time peak power demands, in this system uses a much smaller dc to dc converter working as a controlled energy and maintain the super-capacitor voltage higher than the battery voltage for the most city running conditions. The battery will provide power directly to system when the super-capacitor voltage drops below 0.5 of the battery voltage. In this mode the power diode is forward bias. Braking method of electric bike is help to utilize the kinetic energy so that the power of battery and range of bike is also increase. During deceleration period, bikes are able to store braking energy of motion as a electrical energy and in this period electric motor work as electric generator. This electrical energy is feed to a battery in the bike, and later this energy converted to kinetic energy through the electrical motor during next acceleration mode.**

Keywords: **Battery, controller, dc to dc converters, energy storage, hybrid electric bike, super-capacitor (SC)**

I. INTRODUCTION

A Recycling braking energy is significant way to improve the total energy efficiency of electric bike (EBs). Regenerative braking method of an electric bike helps to proper utilization of power of the battery so that increase the range of the bike. During deceleration period, these bikes are able to recuperate kinetic energy of motion and later this energy converted as a electrical energy with the help of generators. In this mode electric motor works as functions of electric generator. This electrical energy is feed in the battery in the bike, and converted in kinetic energy through the electrical motor during next acceleration period.

During acceleration process the energy has to transfer to charge the super-capacitor. The regenerative braking utilizes the main driving motor to convert K.E. from wheels, finally to charge ultra capacitors. The dissipation of kinetic energy during braking in electric bike can be recovered through the controlling power electronics circuit such that the electric motor operates as a generator.

Ultra-capacitors behave just like regular capacitors, in that the energy stored in their electric field follows the EC = ½CV2 law, where EC, the energy stored, is in Joules, the capacitance C is in Farads and V in Volts. Super-capacitors (SCs) storage system in electric bike is one of the latest improvements in the area of electrical energy storage. The super-capacitors prevent fast battery discharge during acceleration period motor acting like a generator transferring the energy stored inside to the battery. In period of regenerative braking the excessive energy, will be drops in super capacitor, so that it avoided the excessive value of current flow through it.

The energy is recaptured and delivered through the buck-boost converter. Electric Vehicle consists of buck-boost converter circuit as a driver is poor efficiency of recovering braking energy at low speed, which will prevent the efficiency of bike and drive range of bike is decreasing.

In battery-based ESSs, battery power density needs to be high to meet the peak power demand. Although batteries with higher power densities have available, the price of battery typically much higher than the lower power density battery. And solution of this problem is to increase the size of the battery. However, this solution gives to causes an increase in cost. In addition, thermal management is to create the problem for batteries to safely work in high power load time, this period battery not only cool down, but also to the battery warm up in cold temperatures in order to obtain the desired power limits.

This type of problem is solved listed before; in this paper suggest the combination of battery and super-capacitor electric bike. The basic idea of this bike is to combine super-capacitors (SCs) and batteries to achieve a better overall performance. This is because, if we compared to batteries, UCs have a high power density, but a lower energy density. This combination obtains better performance as compare to the use either one of them alone.

Hybrid combination of bike can be classified into two types: passive or active. In the active methods are used one or multiple full size dc to dc converters to interface the energy storage device to the dc link. In other type refer, full size converter the fact that the dc to dc converter create the sole path for the energy flow in the storage device.

In this bike battery pack is directly connected to the dc link and half-bridge converter is set up between the SC bank and the dc link. However, to utilize the power density of the SC, the half-bridge converter must match the SC power level. Although this design is solved the problem of the peak power demands, and battery is still face the problem of frequent charge and discharge operations. To solve all these problems, a new Hybrid bike is proposed. Conventionally, Electric bike used mechanical brake to increase friction of wheel for deceleration period. However, to saving energy, the mechanical brake dissipates much energy then the Electric bike. In regard of this, discusses how to convert the kinetic energy into the electrical and recharged the battery. Thus, the electric brake and energy regeneration have both aims to achieve.

II. REGENERATIVE BRAKING SYSTEM

A. *Working Principle*

A braking mechanism, the in which vehicle brakes are used to absorb the kinetic energy after that this energy is converted to the electrical energy with the help of the generator. In regenerative mode, the motor slow downhill the car. When the forces apply to pedal of brake, the vehicle get slow down and motor works in reverse direction. When vehicle running in invalidate direction the motor act like a generator and thus charge the battery as shown in figure 2. In figure 1 vehicle running in normal condition where motor goes forward direction and absorbs energy from the battery.

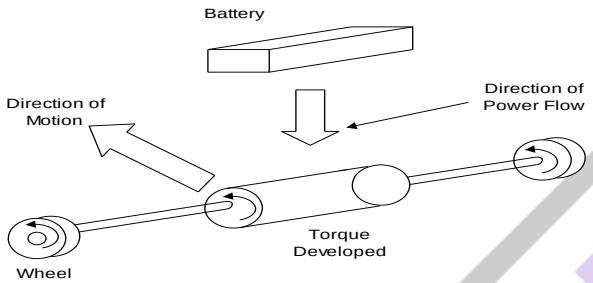

Fig. 1 Normal driving condition

When regenerative braking using in electrical vehicles, it reduces the cost of fuel, increasing the efficiency of the vehicle and emission will be lowered. The regenerative braking provides the braking force during the speed of the vehicle is low and hence the traffic stops and goes thus deceleration required is less in electrical vehicle. If we apply the break in vehicles then power generated goes to the battery and remaining power goes to super-capacitor. Thus, in this process the life span of battery also increases and this braking mode of vehicle is shown in figure 2.

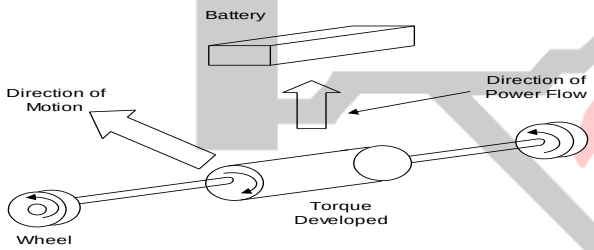

Fig. 2 Regenerative action during braking

In electric vehicle, the brakes work so effectively in driving such that environment stops in cities. The braking system and controller is the main part of vehicles because it controls the whole part of the vehicle of motor. The brake controllers are the function as monitor the speed of the wheel and calculate the torque of vehicle.

III. SWITCHING MODE OF REGENERATIVE BRAKING

The block diagram of hardware implementation is shown below the figure3. In this diagram battery and super capacitor are connected in parallel.

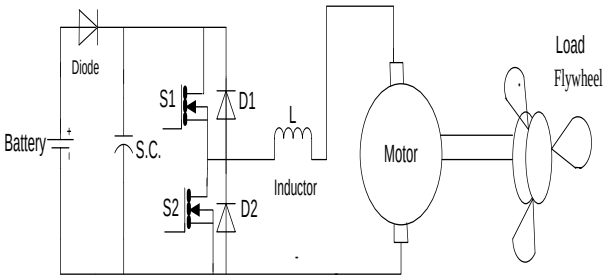

Fig. 3 Block Diagram of Hardware Implementation

Two Power MOSFETs (IRF 460) are connected in two quadrant configuration. The diode is connected in between Battery (12V) and Ultra Capacitor (16V). An External Inductor is connected between armatures of DC motor and joining point of series connected MOSFETs.

Mode I

Initially upper power MOSFET S1 is fed with PWM pulses with variable duty ratio to run the motor at any desired speed. The speed of the motor is controllable by varying duty ratio of PWM gate pulses. The carrier frequency of PWM pulses is kept around 10 KHz to 15 KHz. The motor is connected to the load with flywheel to store the kinetic energy during motoring operation.

Mode II

The lower Power MOSFET S2 is then fed with same PWM pulses from control circuit in order to obtain regenerative braking. During this mode the motor back emf give rise to armature current in reverse direction as compared to what it was during motoring. When the lower MOSFET is turned off during Toff, the current from motor armatures flows through inductor into the Super-capacitor. The Super-capacitor stores the charge and reverses armature current causes braking operation on the motor shaft. The kinetic energy from motor is stored in Electrical energy form in super capacitor. The stored energy of the super capacitor can be reutilized when the motor is again run in motoring mode by feeding gate pulses to upper power MOSFET.
output voltage.

A. *Mode of Operation in Electrical Vehicle*

In the regenerative braking operation, there are two modes as shown below.

Motoring Mode:

I. Conducting Mode

During this mode, current flows from battery to switch s1, to inductor to motor armature and back to the battery.

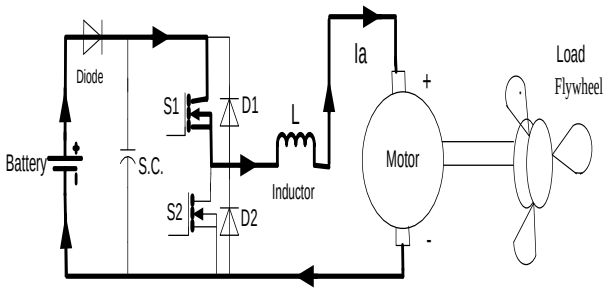

Fig. 4 Conducting Mode

II. Freewheeling Mode

During this mode, armature current circulates through diode d2 and external inductor as shown in figure5.

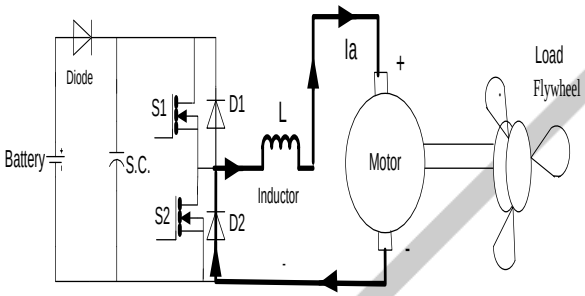

Fig. 5 Freewheeling Mode

Regenerative Mode:

I. Conducting Mode

During this mode, armature current flows through switch s2 and inductor L in reverse direction as compared to motoring mode current.

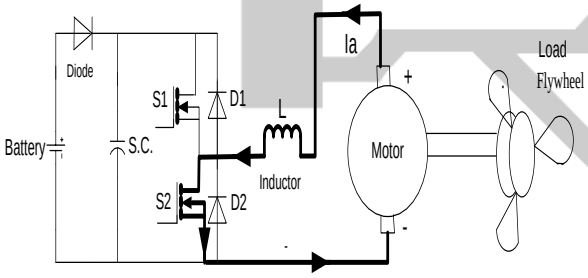

Fig. 6 Conducting Mode

II. Regenerative Mode

During this mode ,the armature current flows from motor armature to super-capacitor C through external inductor L through as shown in fig.7 the super capacitor charges to higher voltage and stores the electric energy supplied by motor causing speed braking operation this mode of operation work as boost converter storing energy from low voltage source to high voltage source.

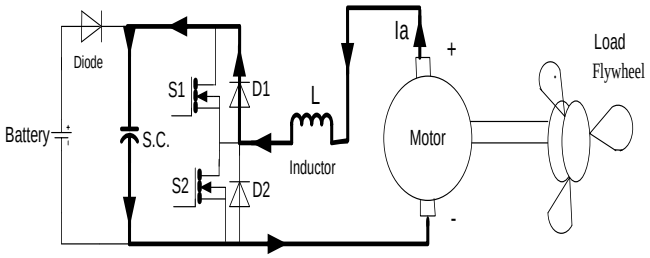

Fig. 7 Regenerative Mode

Motoring mode (Post regenerative braking mode):

During this mode, current will be drawn from super capacitor (SC) and feed store energy back to motor armature through switch s1 and inductor L. during this mode current will not withdrawn from the battery because of reverse biasing of the series diode between battery and super capacitor. The current will withdraw from battery only when the sc voltage goes below battery voltage by 0.7v.

Subsequently the motor goes to motoring mode.

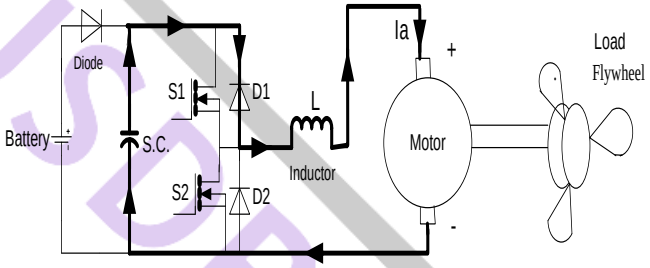

Fig. 8 Post Regenerative Mode

IV ENERGY STORAGE SYSTEM

The storage capacity of energy more relevant in new technology mainly focused on super-capacitor, battery and power converter needed to connect power system in electric vehicles.

B. Battery

In any electric vehicle the battery is main power storage device. There are several types of the battery like as Lead-Acid, lithium-ion, nickel metal hydride etc. Today in electric vehicle lithium-ion battery is more preferable than any other types of battery because it has high specific energy and power.

Battery type	Energy Density (wh/kg)	Number of life cycle	Operating Range Temperature (0C)
Lead acid battery	0-50	400-1200	20-60
Ni-Cd	45-80	2000	40-60
NI-Zn	60-85	1000	20-60
Ion-Li	110-160	500-1000	20-60
Li-Polymer	100-130	3000-4000	0-60

Table.1 Energy density, Life Cycle and Operating Temperature of Batteries

C. Super Capacitor

In the vehicles, the super capacitor plays the very important role. In the vehicles the super capacitor used because of the, they store the energy 20 times larger than normal electrolyte capacitor. In electric vehicle the super capacitor is connected along with the converter because of the balancing the power. The battery and super capacitor are connected in parallel through the controller because of the providing power constantly to motor so that the motor runs smoothly.

Parameter	Lead-Acid Battery	Super-Capacitor
Specific-energy density	10-100	1-10
Specific-power density	<1000	<10,000
Life cycle	1000	>500,000
Charge discharge efficiency	70-85%	85-95%
Fast charge time	1-5h	0.3-30sec
Discharge time	0.3-3h	0.3-30sec

Table.2 Battery Verses Super capacitor Performance

IV. PROPOSED WORK

The system and block diagram of regenerative braking is shown below in figure 9 and figure 10. In this method the the electrical machine operates as a generator.

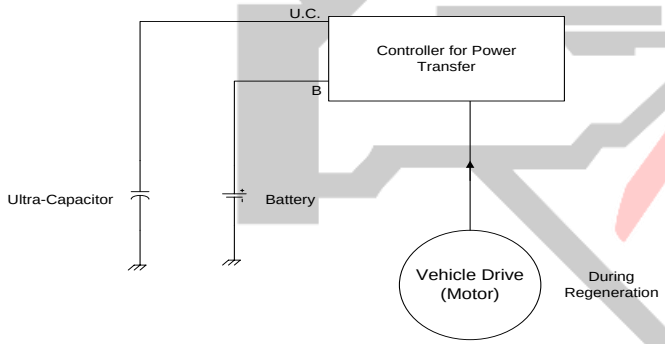

Fig. 9 Model of hardware implementation

In this diagram battery and super capacitor are connected through the controller so that the power providing constantly to controller so that motor runs smoothly. During regeneration operation the motor operate as a generator and kinetic energy is converted to electrical energy and this energy feed back to controller and controller feed the energy battery if the battery is full charged then controller decide and fed the energy in SC. The energy flow direction decides with the help of switching circuit.

Therefore, in future work related to the electric bike will focus on improve the system efficiency in the low driving period. On the other hand, sizing of the dc to dc converter versus SC selection needs to be addressed in order to reduced the cost of the overall system and still maintaining the benefits of bike is low.

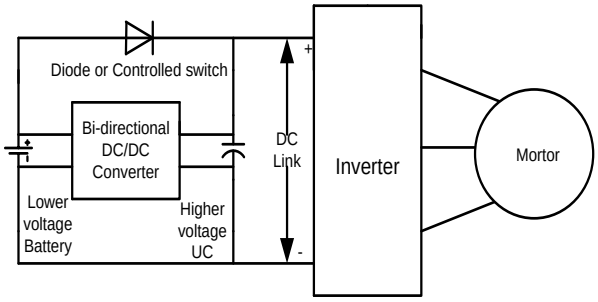

Fig. 10 Block Diagram of Regenerative Braking Configuration

V. CONCLUSION

The regenerative braking is one of the important techniques in electric vehicles generation. In the electric vehicle, regenerative braking has the ability to contribute fuel economy improve by as much as 20%.Todays, the regenerative braking system improved by advanced power electronics devices such as dc-dc converter and storage system like super-capacitor. The lower operating point and environment cost of the electric vehicle is more attractive than a conventional one. These systems are particularly suitable in developing countries like India where the buses are preferred as transportation within the cities.

SC needs to be reduced in order to minimize the cost of the overall system and maintaining the benefits of system is much low.

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BIOGRAPHIES

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