Experimental Verification of the Proposed Super-Capacitor Based Efficient Regenerative Braking Method Suitable for Electric Vehicles and Industrial Drives

Ashish Kumar[1], Dr. S.G Tarnekar[2], Dr. D.R Tutakne[3]
[1, 2, 3] Department of Electrical Engineering
[1, 2, 3] G H Raisoni College of Engineering, Nagpur

Abstract- *– This paper describes the hardware operation and result of the regenerative braking control technology. In electric bike, the regenerative braking is to way of extending the driving range at battery using electric bike. During the braking period, switching sequence of power converter circuit is control to inverse the output torque of dc motor. So that braking energy is returned to the super-capacitor. In this project, the purpose of using super-capacitor is to allow higher accelerations and decelerations of the electric bike with minimum loss of energy and minimum stress (degradation) of the battery. The system is used to MOSFET operated as buck-boost converter; this MOSFET is connected to super-capacitor. At the boost side and other MOSFET is connected to the main battery at the back side. The control of the electric bike is to measures the battery voltage, speed of motor, instantaneous current in both terminals that is load & super-capacitor voltage. When the electric bike runs of high speed, the controller keeps the super-capacitor discharge. If the bike is not running the SC, remains charged as full voltage. And the last purpose of this project is to know the amount of energy stored in the super-capacitor.*

Keywords- Motor, controller, dc to dc converters, energy storage device, Regenerative braking

I. INTRODUCTION

In recent years electric bike plays an important role in the transportation system so that human life goes easy. If compare electrical vehicle and I.C.E the E.V. receiving much attention to the I.C.E. At we see worldwide scenario, now every country to focus on the electric vehicles because of global warming and also rising the price of petrol and diesel. Regenerative braking in which kinetic energy of motor is returned to power supply system. This regenerative braking is possible when motor driven load force run at higher speed then its no-load speed. The motor brake emf Eb is greater than the supply voltage V, than motor armature current flows to reverse direction. The motor begins to operate as an electric generator. The electric bike can have either dc or ac motors. For an ac motor, inverters are used to converting battery dc to ac and then giving to the motor. The gear structure of the electric bike is some as the conventional vehicles both provide variable speed and torques to the vehicle. In this vehicle, battery is the main power sources. An I.C.E vehicle can also converted into E.V. , it involves charging the I.C. engine from electric motor to run the vehicles in this ways initially cost may be increased but it is beneficial and cost effective for users and it better for environment.

In electric bike provide energy to motor to run. While braking provide kinetic energy at motor is converted into heat energy due to friction and this energy lost it. The regenerative braking is recapturing the energy to the system which tries to receive it before it converted into heat. This energy can be stored in super-capacitor and after used when the vehicle is to run.

The super-capacitor is the new technology that allows vehicle to storage 20 times more energy than conventional capacitor. It is important energy storage device. In this paper, the super-capacitor has a capacity of 58 farads, and nominal's voltage as 16.2 volts dc and it compare 25 farad and voltage of 16 volts dc. And also compare the normal capacitor of different ratings. The super-capacitor has provided that high power density and high capacitance. It can not only properties charge or discharge faster but also no limit operating current and gives long life. The energy stored in super-capacitor can be calculated as Ec=1/2CV2 Joules.

In electric bike, braking system are different types. In some bike conventional friction brake have used. In this braking if continuous brakes are applied then it produce friction and stopped the wheel & slow down the vehicle. But in this braking system disadvantage is that the braking is heat up and lost the energy in the form of heat. Another type of brake is anti-lock brake, in this braking system continuous brake is not applied to the bike. In this bike none continuous brake is applied so that stop the bike as needed and other type of braking is regenerative braking. In this braking system controller circuit or motor itself applies the brake by or limit the motor current.

II. FEATURES OF ELECTRIC BIKE

Advantage of electric vehicle

1. It produces zero emission and environment friendly.
2. It produces less noise then I.C.E.
3. It provides fast acceleration.
4. If regenerative braking is applied then the range of vehicle is also increase.
5. Cost of bike is recovered in few year because of save in fuel consumption.

Disadvantage of electric bike

1. The electric bike maximum range as 150 to 200 kilometer sec while the I.C.E range is large up to 300 KM/S.
2. The cost of electric bike is large as compare to I.C.E.
3. Charging time of battery is tane to large.

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.

III. REGENERATIVE BRAKING SYSTEM

A. Working Principle

A braking mechanism, the in which brakes are used to absorb the kinetic energy after that this energy is converted into the electrical energy with the help of the generator. When the forces apply to pedal of brake, the vehicle get slow down and motor works in reverse direction. When vehicle running in inverse 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.

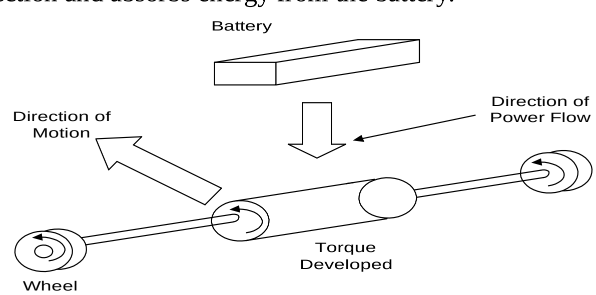

Figure 1. Normal driving condition

When regenerative braking applies in electrical bike, it reduces the cost of fuel, increasing the efficiency of the bike 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.

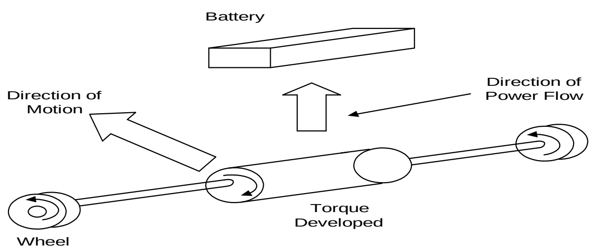

Figure 2. Regenerative action during braking

The braking system and controller is the main part of vehicles because it controls the whole part of the vehicle. The brake controllers are the function as monitor the speed of the wheel and calculate the torque of vehicle.

IV. SWITCHING MODE OF REGENERATIVE BRAKING

The block diagram of hardware implementation is shown below in figure3. In this model battery and super capacitor are connected in parallel in between them one power diode is connected.

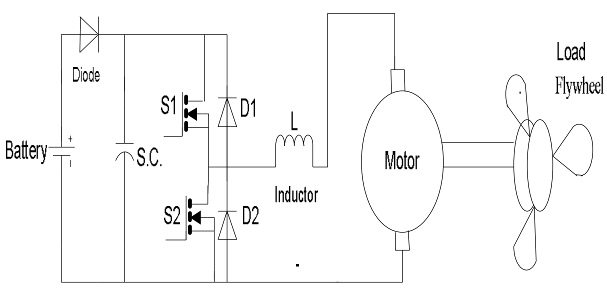

Figure 3. Block Diagram of Hardware Implementation

Two Power MOSFETs (IRF 460) are connected in two quadrant configuration mode. 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 as shown above figure.

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.

V. PROPOSED HARDWARE WORK

The hardware implementation of regenerative braking is shown below figure4. In this hardware, the battery (12V) and super-capacitor (16V) are connected in parallel and in between them two power diode is connected so that the super-capacitor current cannot flow in reverse direction.

Figure 4. Hardware Model

In this diagram the DC Motor (12V) is connected between the battery and power circuit and in between them one boost inductor is connected. In this model battery and super-capacitor are connected in parallel so that the twelve volts battery charged the super-capacitor up to twelve volts which is shown in multimeter.

Figure 5. Hardware Model

In above diagram the multimeter show the super-capacitor voltage. When the motor operates in braking mode the kinetic energy of machines is converted into electrical energy and stored in super-capacitor shown in multimeter which is connected to super-capacitor terminal when applied the brake to motor, the super-capacitor voltage rises 12 volts up to 30 volts. This storing voltage depends on speed of motor.

Figure 6. Control & Power circuit of hardware

In above fig.6 show the power circuit and control circuit of regenerative braking in electrical vehicles/industrial drives. In this model, the speed of motor is control by varying the duty ratio of pwm pulse.

VI. HARDWARE RESULTS

The results of above hardware model of regenerative braking experimental results are shown below in table.

TABLE.1 EXPERIMENTAL RESULTS OF HARDWARE

Motor Speed (in rpm)	Time (in sec) (With Braking)	Time (in sec) (Without Braking)	Super-capacitor Voltage (in volt)	Energy Stored (in joule)
3100	3.79	4.32	30.12	2.012
2465	3.90	4.80	20.80	0.545
2015	3.54	3.71	17.83	0.239
1783	3.29	3.60	16.32	0.132
1627	2.83	3.14	15.06	0.066
1535	3.05	3.21	14.14	0.032
1413	2.77	2.91	13.65	0.019
1234	2.53	2.68	12.99	$6.909*10^{-3}$

VII. ENERGY STORAGE SYSTEM

The super-capacitor is the latest innovation in the fields of storage technology, in this vehicles, battery is the main source of power supply which provide power constantly to the vehicles.

A. Battery

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

Table.2 Energy density, Life Cycle and Operating Temperature of Batteries

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

B. Super Capacitor

The super capacitor plays the very important role in electric bike. In the vehicles the super capacitor preferred more because of; 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.

Table.3 Battery Verses Super capacitor Performance

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

VII. PROPOSED WORK

The block diagram of regenerative braking of electric bike is shown below in figure 7 and figure 8. In this system the electrical machine operates as a generator.

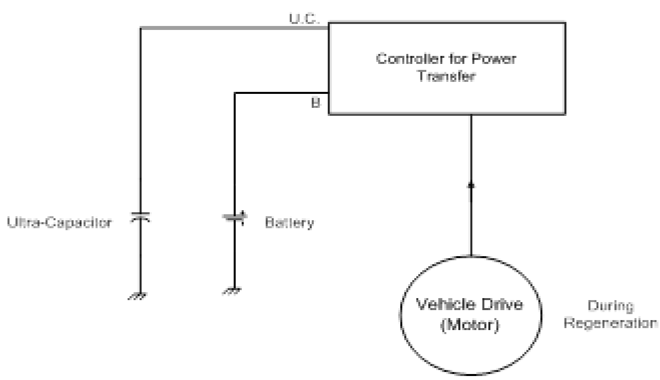

Figure 7. Control & Power circuit of hardware

In above diagram battery and super capacitor are connected through the controller so that the power providing constantly to controller after that motor runs smoothly. During regeneration operation, the machines operate as a generator and kinetic energy is converted to electrical energy then this energy feed back to the controller then controller feed to this energy battery as well as SC. The energy flow direction decides with the help of different modes of operation.

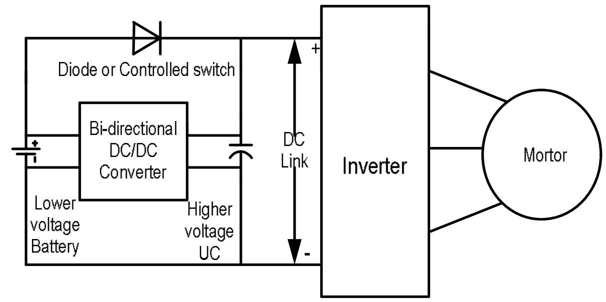

Figure 8. Block Diagram of Regenerative Braking Configuration

VIII. CONCLUSION

In this paper, the prototype model of regenerative braking in electric bike is implemented and braking energy of electric vehicles or industrial drives is stored in super-capacitor. And the stored energy is re-use when the vehicles running in acceleration mode. The super-capacitor is too charge and discharge fast so that the energy flow can be fast and efficient way without much loss. This makes a battery life longer and allows an electric vehicles travel further on a single battery charge. That means the mileage of vehicles increases.

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BIOGRAPHIES

Ashish Kumar is a Research Scholar in G.H. Raisoni College of Engineering with the specialization in Power Electronics and Drives.