Regenerative Braking System Using Ultracapacitor For Electric Vehicles

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Abstract— As we know energy neither be created and nor be destroyed can only converted from one form to another. In this paper we discuss that during braking of vehicle huge amount of energy is lost to atmosphere as heat. It will be good if we could store this energy somehow which is otherwise getting wasted out and reuse it next time we started to accelerate. Regenerative braking technology is crucial for electric vehicle applications where the energy wasted during braking or friction is stored in ultracapacitor and used in other applications. The motor is used as a generator to charge the vehicle's battery. However, the regenerated energy is not fully returned to the battery. Regenerative braking refers to a system in which the kinetic energy of the vehicle is stored temporarily, as an accumulative energy, during deceleration, and is reused as kinetic energy during acceleration it has an energy storage system comprise of the ultracapacitor module and a lithium ion battery connected through a DC/DC converter to a dc motor. These kinds of brakes allow batteries to be used for longer periods of time without the need to be plugged into an external charger. This allows efficient, high power transfer under regenerative braking and acceleration. The ultracapacitor voltage is a key control parameter that affects the efficiency of the overall system.

Keywords—DC brushed Motor; DC-DC converter; Regenerative Braking system(RBS); ultracapacitor; Pulse width modulation (PWM); L293D; H-bridge; MOSFET’s

I. INTRODUCTION

Regenerative braking utilizes the kinetic energy generated by the motor during a brake process. Brakes are employed to stop or retard the motion of any moving body. Thus, in automobiles the brakes are having the most important function to perform. In conventional braking system the motion is retarded or stopped by absorbing kinetic energy by friction, by making the contact of the moving body with frictional rubber pad (called brake liner) which causes the absorption of kinetic energy, and this is wasted in form of heat in surroundings. Each time we brake, the momentum of vehicle is absorbed that it has gained by it and to re-accelerate the vehicle we have to start from the scratch to redevelop that momentum by using the more power from an engine. Ultracapacitors are a new technology that allows us to store 20 times more energy than conventional electrolytic capacitors.

The technology of the ultracapacitors is recently developed, they are not as reliable as the conventional batteries the basic concept of regenerative (“regent”) brakes, which provide braking for the system when needed by converting the available energy to some usable form. Regenerative brake is an energy recovery mechanism which slows a vehicle by converting its kinetic energy into another form, which can be either used immediately or stored until needed. Thus, the generated electricity during the braking is fed back into the supply system, whereas in battery electric vehicles, the energy is stored in a battery. In this paper, a structure for desirable interaction of the battery and ultracapacitor is proposed. In this paper, an auxiliary ultracapacitor bank using a bi-directional DC-DC converter has been implemented. The ultracapacitor has a capacity of 20 farads. The presented RBS is composed of a ultracapacitor module, battery pack, buck converter and a diode. Different operation modes of the proposed RBS are discussed in details. During braking process, using appropriate switching algorithm for the inverter, the DC-link voltage is boosted. Hence, the diode
will be forward biased and the braking energy is directly harvested by the ultracapacitor module without employing additional power converter. The DC-link voltage is adjusted through variation of the duty-cycle of the PWM in the inverter. Hence, when the ultracapacitor is almost charged, regenerative braking can be realized by means of the battery pack. In the proposed method, the regenerative braking efficiency is improved due to elimination of the utilized converters for this purpose. Fast and sudden battery discharge during acceleration, or fast charge during regenerative braking can be avoided with the help of ultracapacitors. The DC-DC converter works in two ways: Boost operation, used for acceleration which discharges the ultracapacitor; and Buck operation used for deceleration (regenerative braking), which charges the ultracapacitor.[5]

II. IMPLEMENTATION AND MAIN COMPONENT OF THE SYSTEM

2.1 Driving DC motor using H-bridge
It consists of four switches, typically implemented with bipolar junction transistors or MOSFETs, and four flyback diodes. An H-bridge can be used to run a DC motor bi-directionally, depending on which switches are closed:

![H-bridge circuit](image)

<table>
<thead>
<tr>
<th>Closed switch</th>
<th>Voltage across motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1, S4</td>
<td>Positive</td>
</tr>
<tr>
<td>S2, S3</td>
<td>Negative</td>
</tr>
<tr>
<td>S1, S3</td>
<td>Zero (braking)</td>
</tr>
<tr>
<td>S2, S4</td>
<td>Zero (braking)</td>
</tr>
<tr>
<td>None</td>
<td>Open circuit</td>
</tr>
</tbody>
</table>

The switch settings not covered in the table (S1 and S2 closed, or S3 and S4 closed, or any set of three or four switches closed) all result in a short circuit and should obviously be avoided. While you can build your own H-bridge out of discrete components, it is usually easier to buy one packaged in an integrated circuit. Apart from reducing your component count, these ICs also make it impossible for you to accidentally cause a short circuit.

An example H-bridge IC is the L293D This chip consists of two (full) H-bridges, each one of which is capable of providing 600mA continuous or 1.2 A peak. It uses two voltage supplies: one high current supply, used to drive the motor, and another logic voltage supply, typically the same voltage used for your microcontroller. The L293D has a single ground for both power and logic. In general an H-bridge is a rather simple circuit, containing four element, with the load at the center, in an H-like configuration. If S1 and S4 are turned on, the left lead of the motor will be connected to the power supply, while the right lead is connected to ground. If S2 and S3 are turned on, the reverse will happen, the motor gets energized in the reverse direction. The mechanical energy of the rotating rotor is converted into electrical energy when the motor act as a generator in RBS. The regenerated
energy can be harvested and fed back to ultracapacitor by applying suitable switching scheme to the H-bridge. The H-Bridge switches to function as a boost converter that boosts the generated back EMF allowing the current to reverse its direction and flow back to the ultracapacitor.[2]

2.2 PWM (Pulse width modulation) signals

PWM is used to control the speed of motor. The use of pulse width modulation to control a small motor has the advantage in that the power loss in the switching transistor is small because the transistor is either fully “ON” or fully “OFF”. To change the motor phase voltage, pulse width modulation is employed.

![Figure 2. Pulse width modulation (PWM) signals](image)

A new fixed frequency digital pulse width modulation controller has been implemented, simulated and experimental verified for motor.

- To run the motor in forward direction voltage input is given to S1 and PWM input is given to S4.
- To run the motor in reverse direction voltage input is given to S2 and PWM input is given to S3.
- A motor can be modelled as a series inductor and voltage source. The motor torque is proportional to current.
- The voltage source is called back-EMF, and it’s proportional to the speed of the motor. This is why a motor draws more current when it is loaded with the speed decreased, the back-EMF is decreased, and it opposes the supply voltage less, resulting in higher current.

The H-bridge arrangement is generally used to reverse the polarity/direction of the motor. It is an electronic circuit that enables a voltage to be applied across a load in either direction. To control the speed of our motor, we use PWM to alternate between positive and negative voltage across the motor, creating an effective “average” voltage. More generally, the average voltage is given by:

\[ V_{\text{avg}} = (2\times DC - 1)\times V_{\text{out}}, \]

Where DC refers to the duty cycle of 1A and \( V_{\text{out}} \) refers to the power voltage. The average voltage varies linearly with the duty cycle, and it is zero at 50% duty cycle and \(-V_{\text{out}}\) at 0% duty cycle.[2]-[5]

2.3 Voltage boost circuit

A boost convertor is a step up convertor that is a DC-to-DC power convertor that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element.
This is the electronic device which can be used to step up the DC voltage.

- Boost converter takes the current from lower DC voltage stores it to a capacitor again during next step current is taken and energy in capacitor increases thus the capacitor voltage increases.
- This increased voltage can use to charge the battery.
- The output voltage depends upon the input voltage and the duty cycle of the boost converter.
- By reducing duty cycle the output voltage may be increased if required.

III. BRAKING WITH ULTRACAPACITOR

Ultracapacitors are electronic devices which are used to store extremely large amounts of electrical charge. They are also known as double-layer capacitors or ultracapacitors. Instead of using a conventional dielectric, ultracapacitors use two mechanisms to store electrical energy: double-layer capacitance and pseudo capacitance. Double layer capacitance is electrostatic in origin, while pseudo capacitance is electrochemical, which means that ultracapacitors combine the workings of normal capacitors with the workings of an ordinary battery. Capacitances achieved using this technology can be as high as 12000 F. Because the voltage strategy of the Ultracapacitor and battery, $D_1$ is usually reverse biased in normal conditions.
In the RBS, the DC voltage must be boosted so that $D1$ is forward biased and the braking energy could be recover by the ultracapacitor module. This is achieved by implementing additional boost converters or using a buck-boost DC/DC converter. Adding another DC/DC converter not only increases the implementation cost, but also decreases the energy transfer efficiency due to the power dissipation of the power electronics interfaces. The MOSFETS on the high arms of the H-Bridge are turned off and the MOSFETS of the low side are pulse width modulated.[5]

As shown in Figure 5. Regenerative braking is achieved by controlling S4 only and switching off all of the remaining switches. In this mode, Q4 is controlled by a separate switching command using a PWM signal. Therefore, it has an ON-time period and OFF-time period.

A. **ON-time period:** During its ON-time period, S4 utilizes the motor’s rotation due to its inertia. Where it creates a path for the current to flow in the opposite direction through Q4 and Q3. During this time interval, the current flows in this closed loop charging the motor’s inductance.

B. **OFF-time period:** During the OFF-time period, Q4 does not conduct current, however the current must maintain its direction. Therefore, the current is forced to flow through an alternate path created by the Q3–Q1 and back to the ultracapacitor to maintain its direction. In this period, the ultracapacitor is charged by the electrical energy generated from the motor’s rotation. Regenerative braking is achieved in this mode of operation [3].
IV. SYSTEM MODEL

The duplex energy system formed the lead-acid battery and ultra capacitor in parallel, and a two-quadrant DC/DC converter is used between them to control the power distribution, so that give a full role of ultra capacitor to balance the vehicle load, and limit the charging rate of battery to capacitor under low power driving condition. That is to say, the ultra capacitor is mainly charged by regenerative braking, if it is not fully charged, then it will be charged by the battery; if it is fully charged, then the battery will be charged by regenerative braking.

When driving in low power, the battery will provide energy to the ultra capacitor if it is not fully charged; in normal driving condition, the battery will provide energy to the driving motor; and when accelerating or climbing, the battery and ultracapacitor together will provide energy to the motor. Whenever the brake is applied the DC motor is still in inertia due to which some amount of energy is stored in the series bank of ultracapacitor. A potentiometer is been used to control the speed of the motor along with the speed control circuit. Now when the PWM pulse is been applied across the motor, the battery is been disconnected and energy is been released from the stored energy of series bank of ultracapacitor.

4.1 Basic idea with the help of flow chart

- The motor is accelerated using 12V battery and speed is controlled by potentiometer.
- H-bridge is constructed for acceleration and deceleration by giving PWM signals.
- Friction is generated while braking.
- Waste energy is stored in bank of ultracapacitor.
- Stored energy can be use for various applications in absence of battery.

![Flow chart of Regenerative Braking System](image)

V. EXPERIMENTAL RESULT AND FINAL OUTPUT

The motor is initially powered by the supercapacitor to operate the drive system in driving mode. A break command is sent to the system, which triggers the driver to operate in regenerative braking mode. The current reverses its direction and is absorbed by the ultracapacitor. The voltage of the ultracapacitor increases and hence the ultracapacitor is charged. 12V is applied by the battery and during each braking session upto 4V is obtained at the output which is doubled i.e. 8V is obtained with the help of voltage booster circuit and stored in ultracapacitor. That amount of energy is used to drive the DC motor. Hence we have got the output of 8V.
Figure 6 demonstrate voltage and current characteristics on charge and discharge of a ultracapacitor. On charge, the voltage increases linearly and the current drops by default when the capacitor is full without the need of a full-charge detection circuit. On discharge, the voltage drops linearly. To maintain a steady wattage level as the voltage drops, the DC-DC converter begins drawing more and more current. The end of discharge is reached when the load requirements can no longer be met.

If we applied 6V power source that is allowed to discharge to 4.5V before the equipment cuts off. By the time the supercapacitor reaches this voltage threshold, a linear discharge only delivers 44% of the energy; the remaining 56% is reserved. An optional DC-DC converter helps to recover the energy dwelling in the low voltage band, but this adds costs and introduces loss. A battery with a flat discharge curve, in comparison, delivers 90 to 95 percent of its energy reserve before reaching the voltage threshold. Thus figure 7, 8 and 9 shows the overall output, Result and observation of our project.
VI. CONCLUSION

The beginning of the 21st century could very well mark the final period in which internal combustion engines are commonly used in cars. Already automakers are moving toward alternative energy carriers, such as electric batteries, hydrogen fuel and even compressed air. Regenerative braking is a small, yet very important, step toward eventual independence from fossil fuels. These kinds of brakes allow batteries to be used for longer periods of time without the need to be plugged into an external charger. These types of brakes also extend the driving range of fully electric vehicles. In fact, this technology has already helped bring us cars like the Tesla Roadster, which runs entirely on battery power. Sure, these cars may use fossil fuels at the recharging stage -- that is, if the source of the electricity comes from a fossil fuel such as coal -- but when they're out there on the road, they can operate with no use of fossil fuels at all, and that's a big step forward. When you think about the energy losses incurred by battery electric hybrid systems, it seems plausible to reason that efficient flywheel hybrids would soon become the norm. But of course it’s not quite so black and white, and further analysis shows that a combination of battery-electric and flywheel energy storage is probably the ideal solution for hybrid vehicles. As designers and engineers perfect regenerative braking systems, they will become more and more common. All vehicles in motion can benefit from utilizing regeneration to recapture energy that would otherwise be lost.

REFERENCES


