Regenerative and Anti-Lock Braking System in Electric Vehicles

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Abstract—**Many accidents are caused when a vehicle is braked hard, causing the wheels to lock up. At such times, the driver has no control over the steering of the vehicle and as a result cannot change the direction of the car. Anti-Lock braking system prevents wheels from being locked up during braking by using a non continuous form of braking (pwm braking), thus giving the driver the control of the vehicle at all times. The kinetic energy of the wheel, which is generally lost in the form of heat, is recovered using a technique called as Regenerative Braking. These two methods together help make a vehicle energy efficient as well as safer to use thus preventing and reducing the number of accidents.**

Keywords—Anti-lock; slip; buck-boost; regeneration; pulse width modulation.

I. INTRODUCTION

When a vehicle is travelling at high speeds and brakes are applied, the wheels are the first to slow down. But the vehicle itself is travelling at speed and has its own momentum which is higher than the wheels due to more mass of the vehicle. Hence the vehicle does not slow down as quickly as the wheels. This difference in speed causes the wheels to lock up. In such a case the driver has no control over the steering and hence the direction of the vehicle cannot be changed. This causes many accidents. Hence, Anti-lock braking is preferred over conventional braking. Anti-Lock Braking System (ABS) takes care of two aspects of braking, wheel lock-up and directional control of the vehicle.

The relative difference between the wheel speed and the vehicle speed is known as 'Slip'. Anti-Lock braking is designed such as to keep the slip to a minimum value so that the wheels do not lock up [1], [3]. The slip value varies between 0 and 1, and when the slip value is 1 that is when the wheels lock up. The design of ABS is based on PWM braking pattern which is a non-continuous form of braking pattern. This is helpful in decreasing the stopping distances while braking as well as giving control of the vehicle to the driver especially on icy and tractionless road surfaces.

When the vehicle is braked, the kinetic energy of the wheel is converted into heat energy due to friction and is lost during the process of braking. Regenerative braking is another form of braking which tries to capture this kinetic energy before it is converted to heat energy and gives it back to the battery [6]. For an electric vehicle, Regenerative braking does the work of braking the vehicle as well as charging the battery thereby increasing the distance that an electric vehicle can traverse in a single battery charge. Here, regenerative braking is done using an IGBT based buck boost converter and a capacitor bank.

II. ANTI-LOCK BRAKING SYSTEM

ABS aims to brake a vehicle travelling at a high speed in such a way that the control of the vehicle always remains in the hands of the driver and the wheels do not get locked up. During hard braking, the slip is at a high value and hence the wheels get locked up.

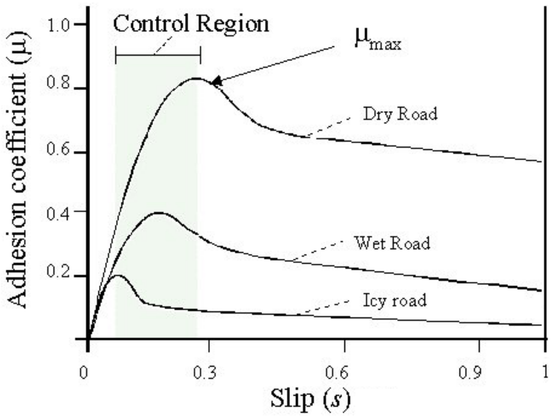

Fig.1: μ-s sample characteristics

The tractive force (F_L) between a tire and the road surface is proportional to the normal load, (F_Z), the constant of proportionality being termed the adhesion coefficient (μ). The adhesion coefficient μ is the ratio of tire brake force at the tire road interface and the normal load acting on the tire, i.e. $\mu = \frac{F_L}{F_Z}$.

Table 1. Values of μ and s for various road surfaces [1]

Road Condition	Max adhesion coefficient (μ_{max})	Optimum Slip (s)
Dry Road	0.85	0.35
Wet Road	0.4	0.2
Icy Road	0.2	0.1

The objective of an Antilock Braking System (ABS) is to control the tractive force applied to the wheels in order to limit the slip, *s*, between the road surface and the tires, and consequently only operate within the stable control region of the μ-*slip* characteristics as shown in Fig.1 [4], [5]. Table 1 shows the typical values of slip at which the maximum adhesion coefficient is obtained, for various road conditions.

We try to keep the slip at its optimum value in the control region during braking so that the tractive force between wheel and road surface remains high and the driver gets to keep the control of the electric vehicle even during hard braking.

III. REGENERATIVE BRAKING

Regenerative Braking is an energy recovery mechanism which saves energy which would have been otherwise wasted as heat due to friction while braking, and stores it in a capacitor bank or a flywheel setup. This energy is then given back to the battery thereby charging it.

Regenerative braking own its own can slow down a vehicle but is not sufficient to completely stop it. Hence it is generally used in conjunction with ABS or conventional brakes. In our circuit, we have used an IGBT based Buck-Boost converter with a Capacitor Bank to stored the recovered energy [2]. The capacitor bank stores the charge temporarily during braking of the vehicle and then the charge is given back to the battery during acceleration when more power is needed.

IV. IMPLEMENTATION

A. *Experimental Test Circuit*

Anti-Lock and Regeneration is tested practically using the test circuit shown in Fig.2. This circuit has an ARM cortex microcontroller. A lead-acid battery pack provides energy to the circuit. The motor is a DC motor and is run through a motor driver IC. The motor is connected to the wheel via a shaft. The wheel setup has a braking mechanism which is controlled using signals from the microcontroller. The Regeneration circuit has a battery pack and a capacitor bank which are connected to each other by an IGBT Buck-Boost converter.

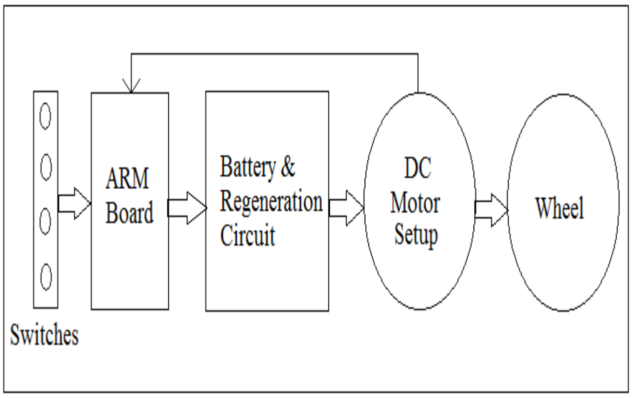

Fig.2: Test Circuit

B. *PWM Circuit*

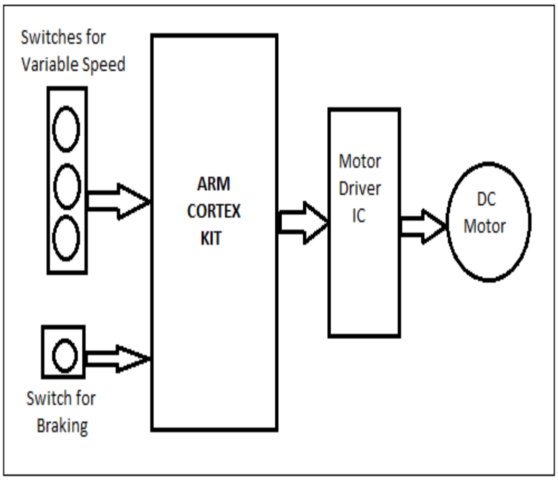

Fig.3: PWM Circuit

The PWM (Pulse Width Modulation) circuit is a part of the experimental test circuit. This circuit (Fig.3) refers to the switches at the port side of the microcontroller and the pwm braking signals given to the braking mechanism in the experimental test circuit. There are 3 switches provided for variable speed function of the motor and these are used to emulate the accelerator pedal of a vehicle. The switches are used for low, medium and high speeds to emulate low, medium and hard pressing of the accelerator. Each successive switch increases the speed of the motor. Only one braking switch is given which is used to show hard braking of the vehicle. On pressing this switch, the microcontroller applies pwm braking to the motor until the motor is completely stopped i.e. the electric vehicle is completely brought to a halt. PWM braking ensures that the motor is stopped swiftly and without locking of the wheel due to hard braking. To show the variable speeds and the braking pattern, a DC Motor is used.

As we see form the waveforms in Fig.4, the speed of the wheel is decreased by applying a PWM braking pattern until

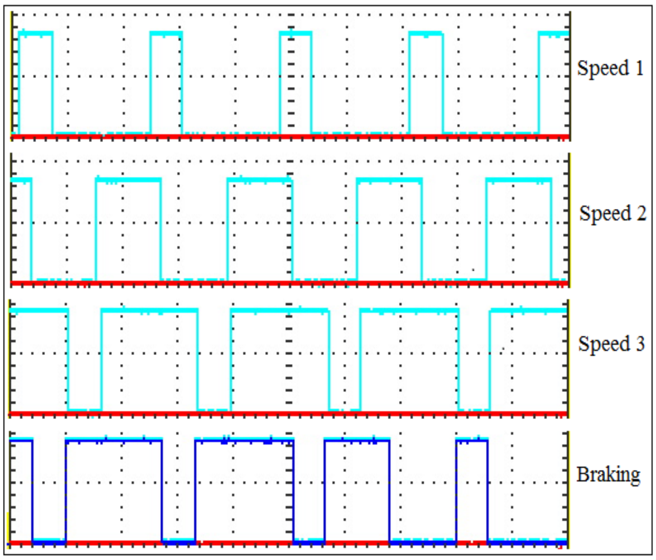

Fig.4: Waveforms for PWM braking

the wheel completely comes to a halt. This allows the tires to better grip the surface, thus keeping the slip value low and at the same time maintain a small stopping distance.

C. *Regeneration Circuit*

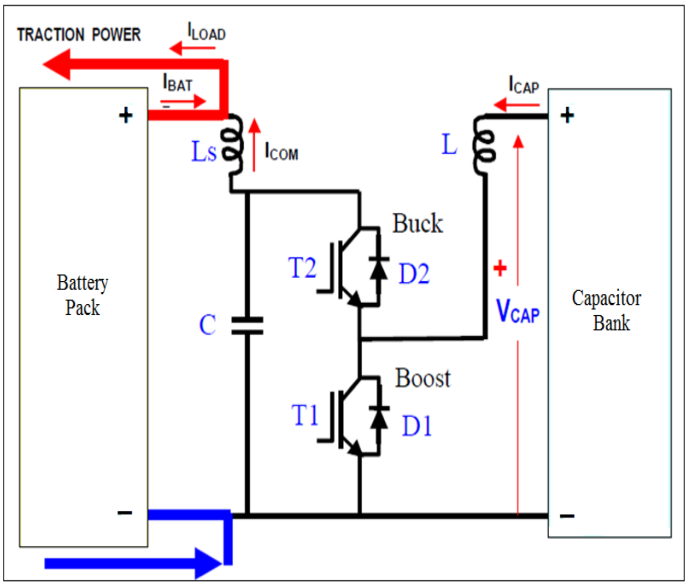

Fig.5: Regeneration Circuit

The Regeneration Circuit (Fig.5) consists of a Battery pack which provides the energy to the circuit. The battery pack used here is a Lead-Acid Battery with nominal voltage of 12 Volts and a capacity of 1.3Ah. A Capacitor Bank is present which stores the energy temporarily which is generally wasted during braking in the form of heat energy.

The Battery pack and the Capacitor bank are connected through the IGBT Buck-Boost Converter. During Buck operation, which takes place during deceleration of the vehicle (when the vehicle is braked), the converter diverts current going to the motor from the battery to the capacitor bank. That operation is accomplished with a controlled PWM (Pulse Width Modulation) signal on IGBT T2. When T2 is switched ON, the energy goes from the battery pack to the capacitor bank, and L stores part of this energy. When T2 is switched OFF, the remaining energy stored in L is transferred inside the capacitor bank.

During the Boost operation (acceleration), IGBT T1 is switched on and off at a controlled duty cycle, to transfer the required amount of energy from the capacitor to the battery pack. When T1 is ON, energy from the capacitor is stored in the inductor L. When T1 is switched OFF, the energy stored in L is transferred into C, through D2, and then into the battery pack. The inductor Ls is placed to soften the current pulses going to the battery pack.

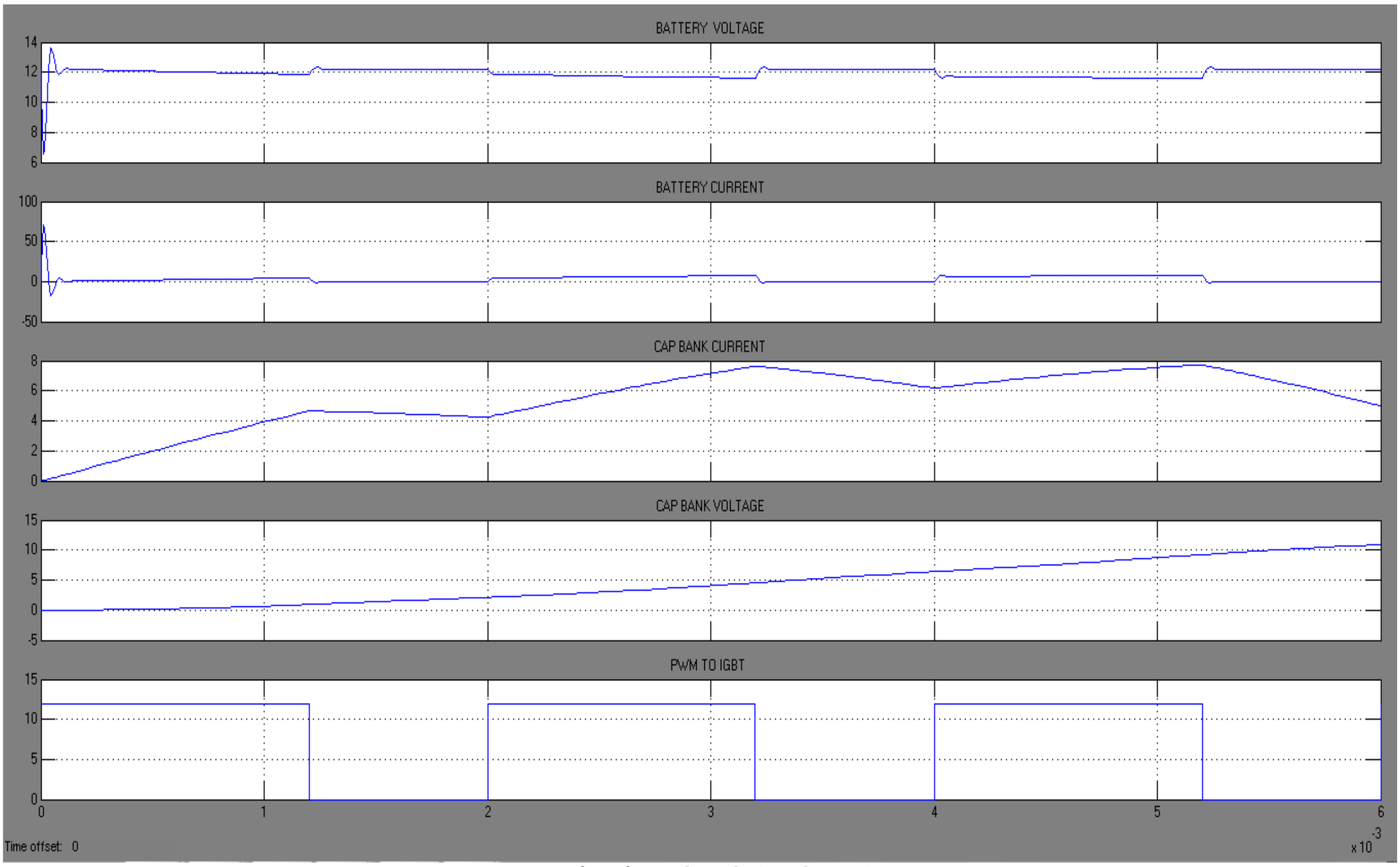

Fig.6: Waveform for Buck Cycle (Deceleration)

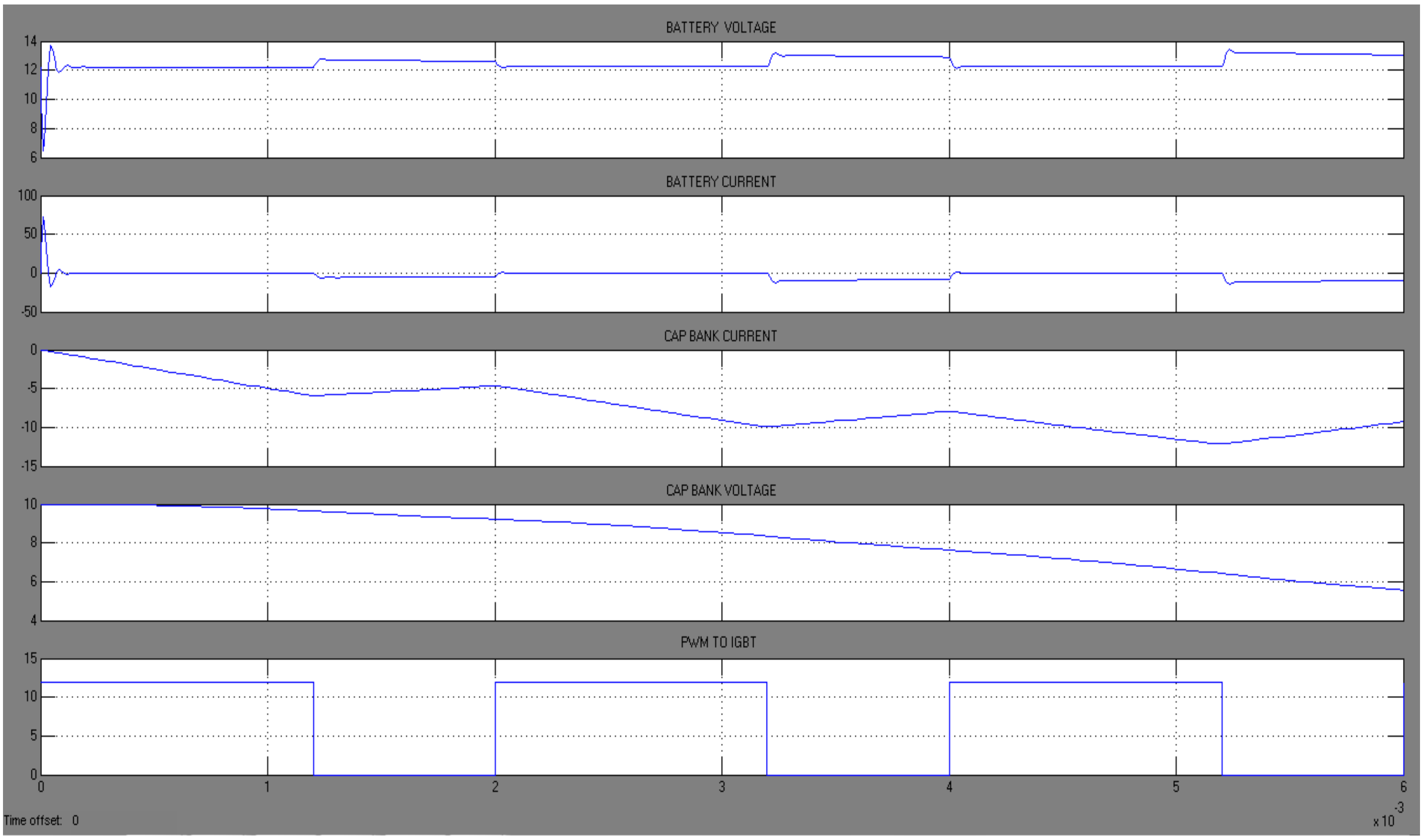

Fig.7: Waveform for Boost Cycle (Acceleration)

V. RESULTS

The waveforms shown in Fig.4 are for the Anti-Lock Braking System using PWM pattern. Using a non-continuous form of braking like PWM, all the disadvantages of hard braking can be overcome while maintaining the car control and reducing the stopping distance for the vehicle.

The simulation of the regeneration Circuit is done using Simulink. The waveforms for the circuit as shown in Fig.6 and Fig.7. During buck operation (when the braking switch in the test circuit is pressed), when deceleration of the motor takes place, the capacitor bank, which is initially has no charge, gets charged due to the current diverted from the motor side. The voltage across the capacitor bank, which is initially zero, increases in successive buck cycles. This charge is stored in the capacitor till the boost cycle takes place. In the performed simulations, the capacitor bank gets charged upto 11 volts. When the motor accelerates, i.e. when speed of the motor is increased using successive switches of the test circuit, the boost cycle is operated and the charge is given back to the battery so that it can provide more current to the motor for acceleration. At this time the voltage across the capacitor bank goes on decreasing. We see that the battery voltages rises from its nominal value of 12 Volts when the charge from the capacitor bank is given back to the battery in successive boost cycles. In the simulation, the battery gets charged upto 13.2 volts after the boost cycle.If any charge still remains in the capacitor bank, it is then used in the next boost cycle.

VI. CONCLUSION

Thus, Anti-Lock Braking provides better control of the vehicle to the driver and does not let the wheels lock up during braking there by reducing the chance of an accident occurring. Also the stopping distance using ABS is reduced in icy or wet road conditions than with conventional friction braking. The Regenerative circuit stores and returns the energy back to the battery which would have been otherwise wasted. This makes a battery last longer as well as allows an electric vehicle to travel further on a single battery charge. Regeneration along with Anti-Lock Braking System makes an electric vehicle energy efficient as well as safer and easier to use.

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