Implementation of Regenerative Braking System in Automobiles

Mohan Kumar and Md. Ehsan Asgar

Abstract This paper proposes an efficient way for implementation of regenerative braking system in automobiles for electric vehicles such as hybrid vehicle. Cost and efficiency of regenerative braking system associated with conversion of heat energy into electrical energy has also being proposed in this paper. This conversion of energy and its storage is done by devices such as capacitor, batteries, and motor which may have been lost as heat while braking.

Keywords RBS · Generator · Efficiency · Energy conversion

1 Introduction

Due to the varying and drastic impact of conventional braking system on environment and to encapsulate losses, development of green technology for braking system is important for automobiles, which prevents emission of particulate matter. This emission of particulate matter can be prevented by development of green technology for automobiles which involves electric cars such as hybrid and semi-hybrid [1]. Regenerative braking system is a solution to reduce this emission of particulate matter, and this is not the only reason. Regenerative braking system also works as a kinetic energy recovery system which helps us to recover a part of energy which may have been lost while braking. RBS does this by converting heat energy into electric energy which is stored in energy-storing devices such as capacitor and battery which may be used for further purpose. It can recover energy up to 10%. This percentage up to which recovery can be done depends upon type of tire, friction on road, speed of vehicles, and brake pedal speed.

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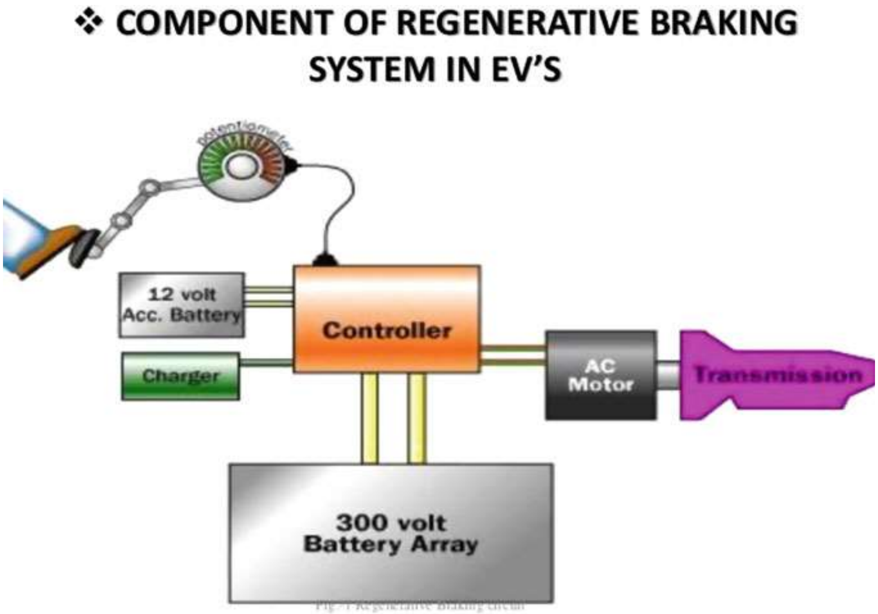
2 Components of the System

1. Energy-converting Devices: PMSM
2. Energy-storing Devices: Capacitor, Batteries
3. Continously Variable Transmission
4. Control System.



2.1 Energy-Converting Devices

For conversion of energy, motors are required. To fulfil this purpose, (PMSM) permanent magnet synchronous motors can be used. This is because the PMSM has many features like high efficiency, compactness, smooth torque, high torque-to-inertia ratio, high pull-out torque, higher power factor, good heat dissipation, good overloading capability, rapid dynamic response, simple modelling and control, low noise- and maintenance-free operation. PMSMs also have a wider speed range capabilities than AC induction motors. PMSMs are rated for 20:1 speed range in open loop and 2000:1 in closed loop (with feedback). The motor runs at constant speed at any torque up to the motor's operating limit, depending upon the supply frequency. Therefore, PMSM is suitable for high accuracy, fixed speed drives. Regenerative braking is an advantage to electric.

2.2 Energy-Storing Devices

The electric used in the car behaves as generator wherever brake is applied. This generator converts the kinetic energy of the car into electricity, and this electricity recharges the batteries of the car. Minimum braking distance of car is ensured with this system; hence, all the kinetic energy cannot be converted to recharge the batteries; some part of the energy is lost as heat. Energy is also lost through the transmission system and in the battery.

2.3 Continuously Variable Transmission

A control loop system with open loop is also required which will continuously monitor the speed of vehicle that at which instant batteries are required to be decoupled as the charge inside energy storage unit has reached the maximum capacity.

2.4 Control System

In order to handle torque and speed demands, a smoothly controlled flow of energy to wheels is required. This can be achieved by CVT which works with flywheel as rotational speed increases when vehicle speed decreases.

3 Working of Regenerative Braking System

RBS is activated whenever vehicle is in motion without the accelerator pedal is being operated, i.e. vehicle going down the slope and while braking. During the period, motors are converted to generator and the some kinetic energy of the vehicle is stored to batteries. This becomes possible as rotating wheels of the decelerating vehicle operate the motor through driveline, the motor become generator, and this produces electricity which recharges the batteries. There is an energy storage unit (ESU) is attached to RBS; its function is to sense the pressure on accelerator pedal. Whenever the pedal is released, the absence of pressure is sensed by ESU, regenerative braking starts, and the batteries are recharged by the motor, which is turned by the wheels. In this case, the friction brakes are not engaged.

There are two more decelerating cases:

1. When foot is not of the throttle, and also not on brake pedal—in this case, the charging of the batteries is slow as the vehicle will slow down progressively.
2. When foot is on the brake pedal—In this case, a more amount of regeneration will occur as the vehicle will slow more rapidly. During light brake pedal application,

Table 1 Effectiveness of different regenerative braking

Energy flow (all in MJ)	High regen.	Medium regen.	Zero regen.
Total acceleration required	32.75	30.90	24.98
Resistance losses	27.90	26.65	18.61
Braking energy	4.86	4.15	6.32
Captured	4.55	3.80	0.00
Losses (due to sink input efficiency)	1.59	1.33	0.00
Stored	2.96	2.47	0.00
Losses (due to sink output efficiency)	0.74	0.62	0.00
Recovered by regenerative braking system	2.22	1.85	0.00
As % of total acceleration energy required	6.78	6.00	0.00
Remainder provided by battery	30.53	29.05	24.98

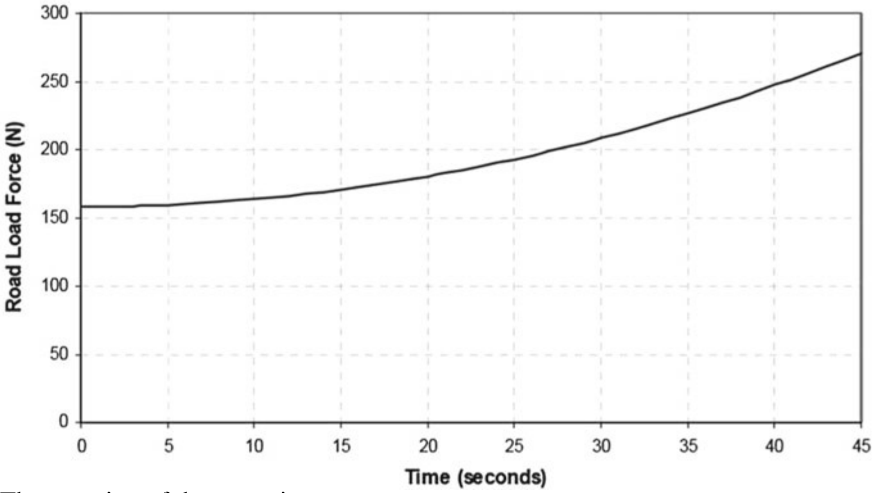
only the IMA motor//generator is slowing the car. With heavier brake pedal application, the conventional friction brakes also come into play. During decelerating, regeneration will go on until engine speed comes to about 1000 rpm.

In this way, braking of the vehicle is obtained.

A voluntary agreement between the European Council and the European Automobile Manufacturers Association will reduce average fleet CO_2 emissions to 120 g/km for new cars by 2012 (Table 1).

These figures show that in the driver only condition, 6.78% of acceleration energy is recoverable through regenerative braking system acting on the accelerator pedal of the Tata Ace electric vehicle. Actuating a brake system in this way is however likely to impact range since momentum is not maintained on gradients or when the driver wants to coast to a reduced speed. With the high levels of regenerative braking torque tested here, the total acceleration energy is increased over the drive cycle due to the resistance in the drivetrain generated by regenerative braking. The recovered energy does not compensate for this due to the rear-wheel-drive configuration which only enables energy to be recovered from the axle which contributes the minority of the total braking effort [2].

Road Load Force (N)



The equation of the curve is:

$$\text{Road Load Force } (N) = (0.0558 * \text{speed2(kph)}) + 157.9$$

Once the vehicle was mounted to the dynamometer, constant speed inputs were applied from the driver's seat with the dynamometer logging wheel torque (which can be converted to road load force). Driving at fixed speeds for 10 s at a time allowed an average force output to be calculated during that time, to compare against the equation for road load force derived from coastdown testing.

The expected values for road load force at 10, 20, and 30 km/h are as follows (calculated from the above equation):

Expected wheel torques		
Speed (kph)	Road Load Force (N)	Wheel torque (Nm)
10.00	163.52	46.19
20.00	180.26	50.92
30.00	208.16	58.81

Range Testing

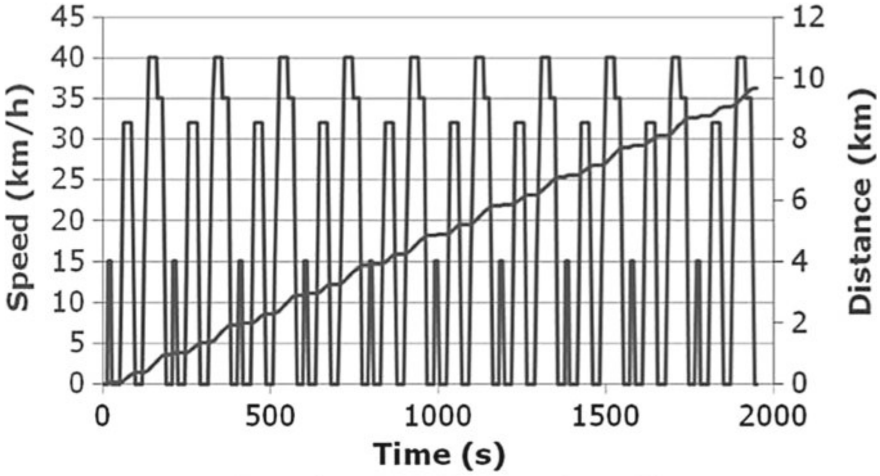
The average range achieved through this method of testing was 42 miles (68 km) over a time period of ~ 3.9 h. The average discharge rate can thus be defined as *C*/4.

The *C*/4 discharge rate can therefore be expected to correspond to a battery pack capacity of 110 Ah. With a nominal battery voltage of 80 V, the maximum battery energy content is calculated as 110 Ah × 80 V = 8800 Wh.

The range of 68 km over a 4 h period corresponds to a 'battery-to-wheel' energy consumption of 8800 Wh/68 km = 129.4 Wh/km.

To measure total 'plug-to-wheel' energy efficiency, charger and battery charging losses have to be taken into account. Assuming 80% charging efficiency, the energy consumption becomes 129.4 Wh/km/80% = 161.7 Wh/km.

A more accurate measure of energy consumption based on units of energy transferred to the vehicle at the charge point was performed by completing a fixed cycle of 10 UDCs. The vehicle was charged to 100% before the test and recharged back to 100% with an energy monitor fitted after the test.



Urban drive cycle speed profile

With an armature current of 65 A and a field current of 16 A (in regenerative braking mode), the amount of forward kinetic energy recovered and reused over a typical drive cycle is 6%. The dynamometer testing has shown that over the full range of the battery capacity, this equates to 9.7 Wh/km of saved energy (6% of 161.7 Wh/km) compared to the same vehicle with no regenerative braking.

12,000 km per year would cost RS. 49,236.43 to recharge over that year at RS. 15.5 per kWh of electricity (using the worse case 264.9 Wh/km plug-to-wheel efficiency). Therefore, a saving of RS. 3000 per year is made to the customer by recovering and reusing energy. In real terms, the benefits to the motorist are through increased range and hence usability as well as decreased wear of friction materials. The benefit to a vehicle manufacturer of successfully implementing regenerative braking is an increase in marketability and sales [3].

4 Conclusion

Implementation of regenerative braking system shows about 25% saving in fuel economy. Theoretical investigation reveals that up to 10% of acceleration energy is recoverable. Regenerative braking system in vehicle will improve its stopping distance. Regenerative braking system if implemented in vehicle will not make it costly and moreover environmental issues can be resolved.

Developing countries like India can move in direction of implementation of regenerative braking system in automobiles due to which major environmental problem of emission of particulate matter in nature can be resolved to much greater extent and will make it more attractive and preferable.

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