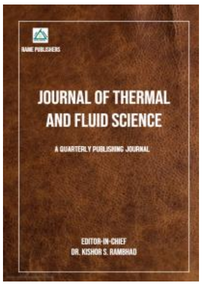


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# Analytical Treatment for Design of Regenerative Braking System

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*Abstract*— **As we know electric vehicle attracting lot of attention. But as we know there is a certain limitation to electric vehicle, like driving range, battery replacement electricity isn't free etc. because we are in the initial stage of this EV'S era. In this paper we research about regenerative braking system. Which will help to increase the driving range of vehicle which is one of the advantages of EV'S. As we know cars like Go-kart which made for specially for racing required desired driving range and battery. RBS is a technique through which we can restore certain amount of energy. As per the French philosopher Voltaire has quoted that "with greater power comes with great responsibility" on the same ground "with superior speed comes the need of an efficient and effective braking system". We analyze the braking system for the national level inter-college Go-kart competition. Which can efficiently help the vehicle to stop.**

***Keywords***—regenerative braking, design, fabrication, analysis, BLDC motor

## I. Introduction

Regenerative braking is an energy recovery technology that slows a moving vehicle by transforming its kinetic energy into a form that can be used right away or stored till later. Regenerative braking employs an electric vehicle motor as a generator to return most of the kinetic energy lost during deceleration to the vehicle's battery.

The principle of physics asserts that energy cannot be destroyed; it can only be moved from one form to another. Pressing the brake pedal causes a set of brake pads in each wheel to contact the surface of a brake rotor in a classic braking system.

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Regenerative slowing mechanisms require further exploration to foster a superior framework that catches more energy and stops quicker. As the time passes, architects and specialists will consummate regenerative stopping mechanisms, so these frameworks will turn out to be increasingly normal. All vehicles moving can profit by these frameworks by recovering energy that would have been lost during slowing down measure and in this manner lessening fuel utilization and expanded effectiveness.

The Perpetual magnet BLDC engines are being utilized all the more much of the time in electric vehicles because of their strength, unwavering quality and high proficiency. One of a best benefit of a Lasting magnet BLDC engine is that it can deliver a higher voltage at lower rpms than different engines or generators. This will assist with utilizing this engine as a generator in the regenerative stopping mechanism. In an electric vehicle, regenerative braking system serves to charging the battery by moderating energy, in this manner expanding the scope of the vehicle.

The regenerative slowing down is one of the significant frameworks in electric vehicles age. The regenerative slowing down can save the waste energy up to 8-25%. The exploration says that regenerative slowing down is as of now in utilized in numerous Electric Vehicles. Because of the petroleum cost increment brings about exploration and progress in energy protection. It likewise improves the fuel utilization by 33%. The outcomes say that the force driven by the vehicles is estimated. Electrical force created by engine, generator and battery is exceptionally valuable and thus it ought to be utilized in electric vehicles.

## II. OBJECTIVE

- Recapture the energy byproducts that results when the brakes are applied.
- To fabricate most efficient and high-quality regenerative braking system
- To reduce the overall weight of vehicle and to increase stability.
- Regenerative Braking system aim to recover, store and reuse same of the vehicle braking energy to improve fuel efficiency or boost the range of electric and hybrid vehicle.

## III. BLOCK DIAGRAMS

In this investigation, the framework was sent on a front-wheel drive electric vehicle and the design is appeared in figure 1 the front hub was driven by a perpetual magnet coordinated engine through a transmission with steady stuff proportion and a differential.

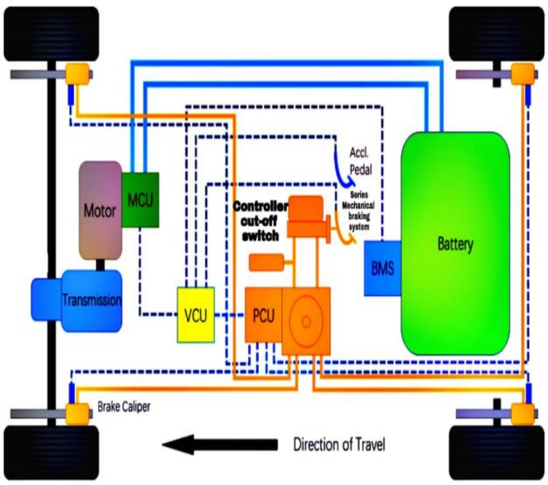


Figure 1. Layout of the powertrain and cooperative braking system

The engine was constrained by an engine control unit (MCU), which had driving rationale and force hardware. A high-voltage lithium battery load with battery the executive's framework (BMS) was utilized to give energy to foothold to push the vehicle and store the electric energy recuperated. Each wheel was furnished with a circle brake with a water driven pressing factor sensor and the pressing factor in each brake chamber was constrained by a pressure driven control unit, which was just had an actuator with some solenoid valves and electric siphons inside. An extra PCU (pressure control unit) was executed to control the activity of the valves and siphons. Every one of the three control units (MCU, BMS, PCU) were associated with a vehicle control unit (VCU), which can perceive the driver's goal by getting and examining the signs from the gas pedal and brake pedals and control every one of the parts by sending solicitations to other control units.

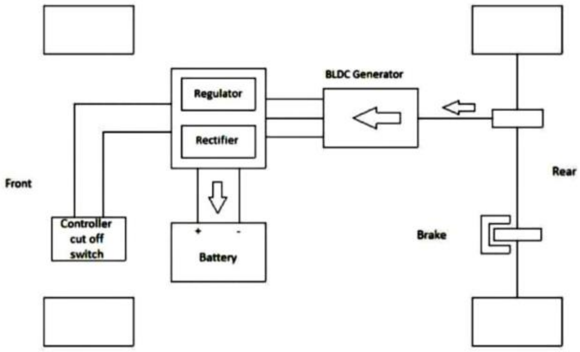


Figure 2. Regenerative braking system powertrain and its circuit

The above Figure (2) shows the implementation of the regenerative braking system of an electric vehicle with rear wheel drive and rear wheel braking.

In this type of regenerative circuit, the resistance of the motor is used as the brake which in turn also acts as a generator thus charging the battery on the expense of slowing down the vehicle. But for effective braking the mechanical brakes are to be used by the driver.

The brake lever in the go-kart is as made that it first actuates a controller cut-off switch and later it actuals the mechanical brake if needed. The function of the cut-off switch is to cut-off the main current supply from the controller to the BLDC Motor. When the current is cut-off, the controller can no more control the motor in any way. But at the same time the BLDC Motor acts as a generator and uses the momentum of the vehicle to rotate the shaft of the motor. In the motor an opposing force is generated as it produces current. This opposing force acts as a brake which helps slow down the vehicle. The flow of current is shown in the Figure 2. When the vehicle is accelerating the current flow is as shown in the Figure 2.

At the same time the motor produces an AC voltage. But this AC voltage cannot be fed directly to the batteries. Hence, this regenerative braking motor controller is embedded with a voltage rectifier circuit. This rectifier circuit converts AC voltage to DC voltage. The charging system doesn’t end here. As the motor is powered by a 48v battery pack, a minimum if 55v is needed to charge the batteries. As the regeneration system will not only work at high speeds but also at lower speeds. And it’s not possible for a generator to produce a same voltage with a varying rpm of the shaft. Hence, a voltage regulator circuit is also included in the controller circuit which will regulate the voltage and help charge the battery even in low vehicle speeds with a constant voltage of 55v.

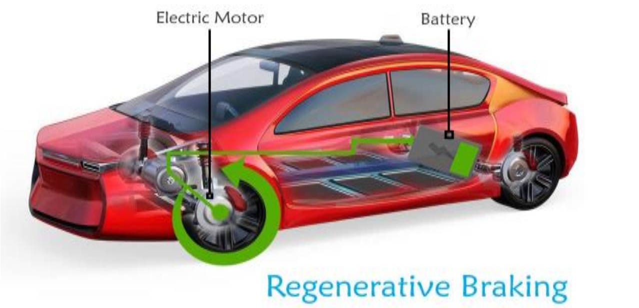


Figure 3: Actual image of regenerative braking system

Allow us to think about that as a vehicle has a three stage AC Induction engine as the engine for its drive. From the engine qualities, we realize that when a three-stage acceptance engine runs over its simultaneous speed, the slip becomes negative and the engine goes about as a generator (alternator). Under pragmatic conditions, the speed of an enlistment engine is in every case not exactly the simultaneous speed. The coordinated speed is the speed of the pivoting attractive field of the stator created because of the association of three stage supply. At the hour of turning over the engine, the EMF instigated in the rotor is most extreme. As the engine turns over pivoting the EMF incited diminishes as a component of slip. Exactly when the rotor speed shows up at the planned speed, the EMF activated is zero. Now, on the off chance that we attempt to turn the rotor over this speed, EMF will be incited. For this situation, the engine supplies dynamic force back to the mains or supply. We apply brakes to lessen the speed of the vehicle. For this situation, we can't expect the rotor speed to surpass the coordinated speed. This is the place where the part of engine regulator comes into the image. For the arrangement reason, we can imagine like the model given beneath.

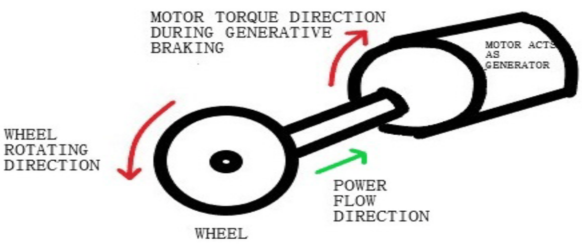


Figure 4: power flow in wheel

Allow us to accept that the engine is turning at 5900 rpm and the stockpile recurrence be 200 Hz when we apply brake, we need to diminish the rpm or bring it down to nothing. The regulator acts as indicated by the contribution from the brake pedal sensor and completes that activity. During this interaction, the regulator will set the inventory recurrence not exactly the 200 Hz like 80 Hz. Along these lines the simultaneous speed of the engine becomes 2400 rpm. From the engine regulator point of view, the speed of the engine is more than its coordinated speed. As we are diminishing the speed during slowing down activity, the engine currently goes about as a generator until the rpm diminishes to 2400. During this period, we can remove power from the engine and store it in the battery or capacitor bank. It is to take note of that the battery keeps on providing capacity to the three stage enlistment engines during the regenerative slowing down measure. It is on the grounds that the enlistment engines don't have an attractive motion source when the stock is OFF. Consequently, the engine when goes about as a generator draw receptive force from the stockpile to build up the transition linkage and supplies dynamic force back to it. For various engines, the standard of recuperating the active energy during regenerative slowing down is extraordinary. Perpetual magnet engines can go about as a generator with no force supply since it has magnets in the rotor to create attractive motion. Essentially couple of engines have remaining attraction in it which wipes out the outside excitation needed to make attractive motion.

In a large portion of the electric vehicles, the electric engine is associated uniquely to the single drive pivot (generally to the back tire drive hub). For this situation, we need to utilize a mechanical slowing mechanism (water powered slowing down) for the front wheels. This implies that the regulator needs to keep up coordination between both the mechanical and electronic slowing mechanism while applying the brakes.

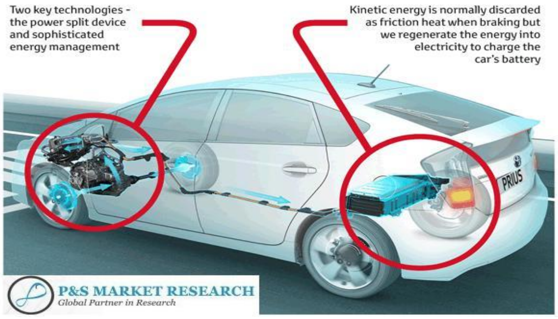


Figure 5: Power splitting

## IV. TYPE OF REGENERATIVE BRAKING SYSTEM

### I. *Serial braking system*

Serial regenerative slowing down depends on a blend of grating based flexible stopping mechanism with a regenerative slowing mechanism that moves energy to the electric engines and batteries under an incorporated control methodology. The general plan is to assess the deceleration needed by the driver and disseminate the required slowing down power between the regenerative slowing mechanism and the mechanical slowing mechanism. Serial regenerative slowing down could give an expansion of 15-30% in eco-friendliness. It requires a brake-by-wire framework and has steadier pedal feel because of good force mixing capacity.

### II. *Parallel braking system*

Parallel braking system is based on a combination of friction-based system and the regenerative braking system, operated in tandem without an integrated control. The regenerative slowing down power is added to the mechanical slowing down power which can't be changed.

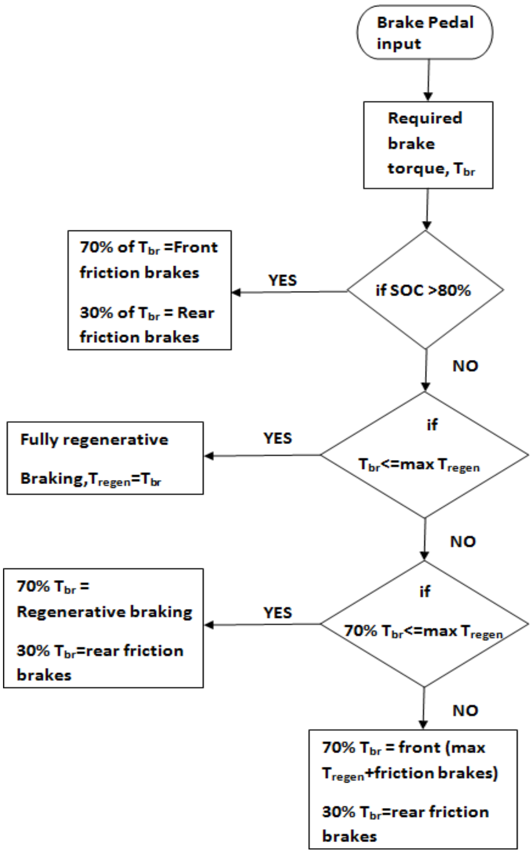


Figure 5: chart representation of serial regenerative braking (front wheels)

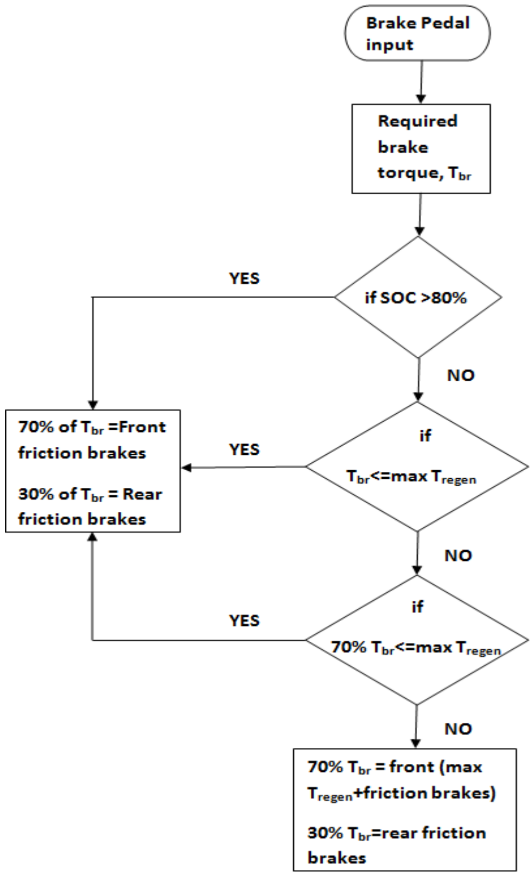


Figure 6: flow chart representation of parallel regenerative braking (front wheels)

The regenerative slowing down power is expanding with the mechanical slowing down power. The starting pedal travel is utilized to control the regenerative slowing down power just, the typical mechanical slowing down power isn't changed. The regenerative force is controlled by thinking about the engine limit, battery condition of charge SOC, and vehicle speed. The regenerative slowing down power is determined from the brake control unit by looking at the requested brake force and the engine force accessible. The wheel pressure is diminished by the measure of the regenerative slowing down power and that provided from the water driven brake module. Equal regenerative slowing down could give an expansion of 9-18% in eco-friendliness. It tends to be added onto a customary stopping mechanism. Anyway, it could bargain the pedal feel and consequently requires more work in accomplishing great force mixing.

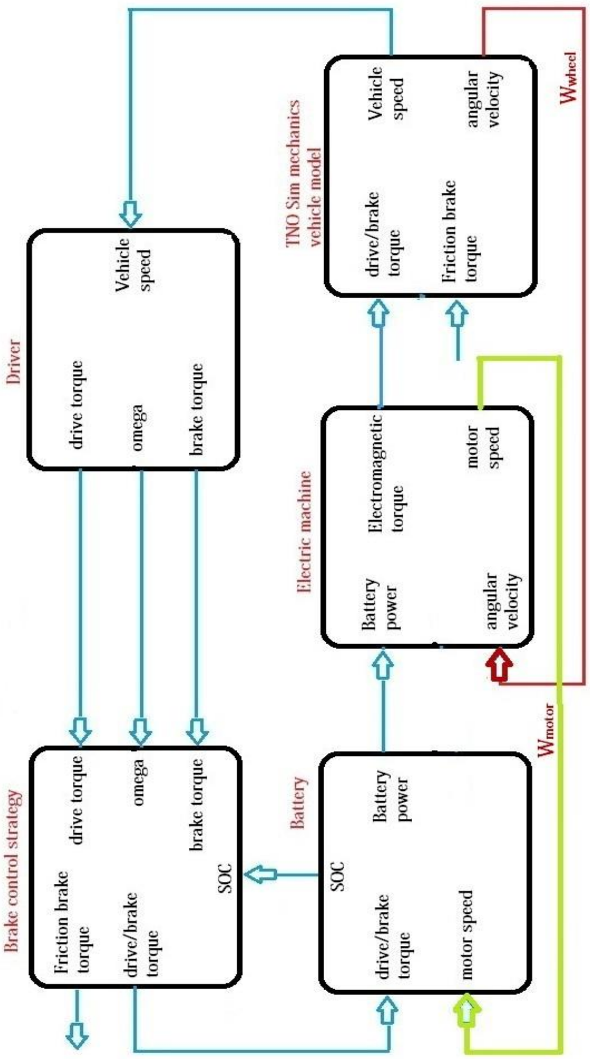


Figure 7: Schematic representation of the entire electric car model

## V. Analytical Treatment

Pedal ratio = 4:1

Manual force applied=160N

Mass of vehicle = 170 Kg

Velocity = 50km/h =13.88m/s

Weight distribution: 40% for front and 60%for rear.

### *A. Double pistone caliper calculations*

Gross weight of vehicle(w)=170×9.81=1667.7N

Pedal ratio=4:1

Brake line pressure:

Bp = (pedal ratio× force on pedal/area of master cylinder)

= 8.14MPa

Clamping force (F) = brake line pressure ×piston area No. of piston

$$= Bp \times (\frac{\pi}{4} \times d^2) \times 2$$

= 8249.19N

Rotating force (Rf)= F× No. of piston× μ

(μ=coefficient of friction between disc and pad)

= 4949.514N

Braking Torque (Tb)= Rf × disc radius

=420.70N-m

$$\text{Braking Force (Fb)} = \frac{Tb}{\text{Tire Raius}} \times \mu$$

=2559.73N

$$\text{Deacceleration(a)} = \frac{-Fb}{m}$$

$= -15.05\ m/s^2$

$$\text{Stopping distance(S)} = \frac{V - u2}{2a}$$

= 6.40 m.

$$\text{Stopping Time} = \frac{v}{g}$$

= 1.41sec.

Total K.E. = $(1/2) \times mv^2 \times k \times r$

= 4421.41 J

$$\text{Total Braking Flux} = \frac{\text{Total K.E.}}{\text{Toping Time}}$$

= 3135.75 W

$$\text{Total Heat Flux} = \frac{\text{Total Braking Power}}{\text{Area}}$$

$= 22.87\ KW/m^2$

Regenerative Braking Calculations

Mass of vehicle = $M_v$ = 170Kg

Frontal Area = $A_f = 1m^2$

Drag Coefficient = $C_w = 0.35$

Radius of wheel = 0.2794m

Air desity =1.226

Rolling Resistance Coefficient = 0.0012

### A. *Regenerative Braking force Calculations*

Deacceleration of vehicle

Power $P_e$ = 4 kw

Max. Current =$I_{max}$ = 110amp

Min. Voltage = $V_{min}$ = 40 v

Max. Motor torque, $15.5 \times \frac{400}{100} = 62$

Maximum regenerative Torque

$T_{reg} = T_{motoramx \times Gear\ Ratio}$

= 190.34

Required brake Force

$F_x = m\ w + ½\ þ\ C_w A_f\ v^2 + C_{roll}\ mg$

Required brake torque

$T_{b\ =} F_x \times R_w$

Tire Braking Force

$= F_x = \mu MV_g/2$

Sliip Ratio

$=K=R_w\ .\ W\text{-}Vx\ /V_x$

### B. *Normal Force On Tire*

$F_z = F_x/\mu$

μ can be taken from table of μ vs slip ratio and here we taken as

#### a. *Case 1*

(2 wheel braking at deacceleration )

Suppose vehicle comes to rest from 65 km/hr ar deacceleration of -3 m/s.

Here u=18.05 m/s and $a=-3m/s^2$

Required braking force =

$Fx= 170\times(-3)+1/2(1.226\times0.35\times18.05^2)$

$+ (0.0012\times170\times9.81)$

= -438.1 N

The force per wheel on rear axlr

$F_x$= -438.1/2 = -219.0.5N

The required braking torque per wheel

= -219.05×0.2794=-61.20N

Since required braking torque per wheel is below maximum regenerative torque couple of generators $T_{req}$ braking can be fully regenerative depending upon braking strategy applied.

#### b. *Case 2*

(2 wheel braking at large deacceleration)

Suppose vehicle come to rest from 18.05 m/s at deacceleration of -3m/s.

Required braking force

$F_x = (170\times-8) + 0.5(1.226\times0.25\times18.05^2)$

$+(0.0012\times170\times9.81)$

= -1288.1 N

Force per wheel = F/wheel

= 644.05 N

Required braking torque per wheel = $T_{wheel}$

=1288.1/2=644.05N

Hence required braking torque is below maximum regenerative torque. Hence here braking can be fully regenerative depending upon braking strategy applied.

#### c. *Case 3*

(Max. deacceleration with regenerative braking) Here maximum regenerative torque given by the generator is given as

$T_{reg}$ = 190.34 N-m = max. torque per wheel

The torque per wheel =(190.4/0.2794)=681.24N

The total longitude force = 681.24×2=1368.48N

The maximum deacceleration possible

$A=F_{xtotal}$ – Croll mg /mv

$= -8.002\ m/s^2$

Here max. regeneration possible with regenerative braking is $a= 8.002\ m/s^2$

## VI. Conclusion

Analyzing all the parameters and with the help of the experimental values from the reference papers it is clear that only 10% to 15% of the total lost energy can be recovered from this system. There are more ways to optimize the energy recovery with the help of more advanced circuits. Using a regenerative circuit, the range of the vehicle increases. The decision to go full electric was due to the ill effects of IC engines such as air pollution, global warming and also the depleting oil reserves. The Government of India has recently passed a new resolution that no IC engine cars will be sold in the country from the year 2030 onwards. Also, with better technology now being available, it is economically feasible to run a vehicle on electrical power.

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