

# REGENERATIVE BRAKING SYSTEM IN ELECTRIC VEHICLES

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**Abstract** – In this paper, a easy but useful method of regenerative braking in electric vehicle is proposed. Regenerative braking is an most excellent way for electric vehicle to expand their driving capabilities. The regenerative braking plays an vital part to maintain the vehicle's strength and getting better energy. Electric vehicle's use mechanical brake to boost the roughness of wheel for the deceleration purpose. However from the point of view of saving energy, mechanical brake increase out much energy while the EV's kinetic energy is renewed into the thermal one. The braking system for a vehicle is based on hydraulic braking technology. Thus, this traditional braking methodology causes a lot of wastage of energy since it produces unwanted heat during braking. Thus, the creation of regenerative braking has rise above these disadvantages in addition it helps in save energy and provide higher efficiency for a car. The main aim that has been focus on having influence on brake energy regeneration that is usable is discussed.

**Key Words:** Electric Vehicle, Regenerative Braking, Motor, Generator.

## 1. INTRODUCTION

Now a day's electric vehicles (EVs) have traditionally much attention for alternate to traditional internal combustion engine(ICE) vehicles[1]. The development of hybrid and EVs become mostly popular. That can be seen due to highly increased awareness of global warming and also rise in cost of petrol prices. Thus also due to increased in air pollution which is concern in environment and increase in oil prices, the EVs is the first and last choice for the transportation. In battery operated EV, battery is the only source for energy and these batteries are facing problem such as less charging and recharging cycles also poor response in driving range[10].

The mention problems are overcome by using battery with any one of the energy source such as ultra capacitor, flywheel, electrochemical batteries and etc [10]. Some processes are introduced to overcome this problem; one of them is regenerative braking. Regenerative braking is the process by which some of the kinetic energy is stored in the vehicles, which is

translated and kinetic energy is stored in the battery and ultra capacitor during deceleration[12]. The regenerative braking does not function all time in a plain road surface area. It is seen in those road ways where vehicle have to apply brake on speed breaker, pits on road and on slope where vehicles have to apply brake.

The regenerative braking is observed only when the battery is full charge braking needs to be effect by the energy, thus mechanical brake in the EVs are needed. EV's use mechanical brake for the increase the roughness of wheel for the decelerate purpose. From the position of saving energy, the mechanical brake dissipate much energy, since the EV's kinetic energy is renewed to electric energy. The easy to control motors are capable of regenerating. In two-wheelers EVs, generally mechanical brakes are used for stopping or decelerating the speed of vehicles; all kinetic energy stored in the vehicles at the time of braking is lost [7]. The kinetic energy which is lost at the time of braking can be converted back into electrical energy and stored in battery and ultra capacitor. This energy will be stored in battery if managed properly and controlled carefully without causing any problem to the motor, the drive and the battery. Now till date demand for Electric Vehicles starts increasing according to market.

## 2. REGENERATIVE BRAKING SYSTEM

### 2.1 Working Principle

Regenerative braking is a brake method to use mechanical energy from the motor and convert kinetic energy to electrical energy and give back to the battery. In the regenerative braking mode, the motor slows downhill the car. When we apply force to pedal of brake, then car gets slow down and motor works in reverse direction. When running in invalidate direction motor acts as the generator and thus charge the battery as shown in figure 2[9]. Thus in figure 1 the car which is running in normal condition where motor goes forward and takes energy from the battery.

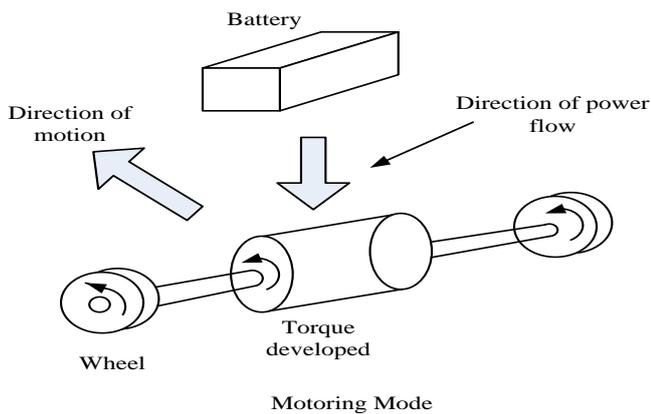


Fig-1: Normal driving condition [9].

When using regenerative braking in electric vehicles, it reduces the cost of fuel, increasing the fuel financial system and emission will be lowered [9]. The regenerative braking system provides the braking force during the speed of vehicles is low, and hence the traffic stop and go thus deceleration required is less in electric vehicles.

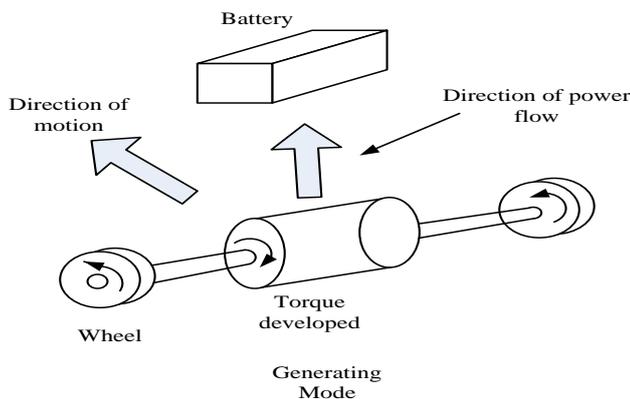


Fig-2: Regenerative action during braking[9].

This brakes work so effectively in driving in such environment so as to stop in cities. The braking system and controller is the feeling of the structure because it controls the whole part of vehicles of the motor. The brake controller functions are monitor the speed of the wheel, hence calculate the torque, electricity which is to be generated and rotational force thus to be feed to batteries. When we apply brakes the brake controller, it controls and direct the electrical energy which is formed by the motor to the batteries [12].

## 2.2 Operation Of Motor In Electric Vehicles.

Figure 3 shows the basic the same circuit of a 3 phase brushless DC motor, the motor is driven by an inverter which is fed from a source battery. As shown in the figure  $R_a, R_b, R_c$  are the phase resistances,  $L_a, L_b, L_c$  are the phase inductance and  $e_a, e_b, e_c$  are the back- EMFs in the A,B,C phase respectively. D1 to D6 are the freewheeling diode and S1 to S6 are the switching devices.

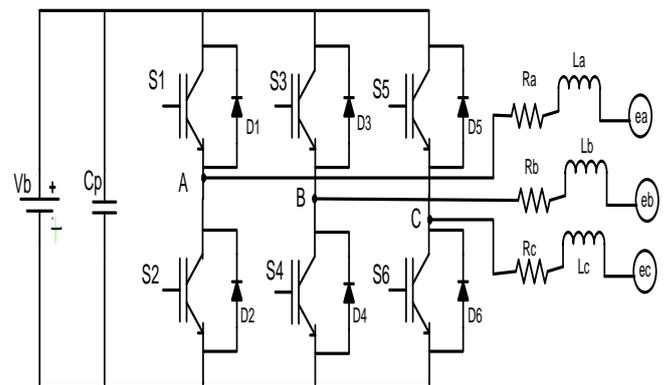


Fig-3:Equivalent circuit of an inverter driven 3-phase PM BLDC motor [7].

The ideal back-EMF, phase current and developed torque profiles of PM BLDC motor is a complete commutation cycle spanning 360° electrical consists of six equal intervals. The switches S1 to S6 are operated in a sequence using a control circuit based on position received from the rotor position sensors such as hall-effect sensors. To control the torque which is developed by motor, control by the inverter circuit shown in figure 3. The process of regenerative braking is shown by the arm under the IGBT bridge whose switched movements are correspondence to the working module of motor [6].

## 2.3 Control System For Evs

The motor which is use in electric vehicles is BLDC(Brushless DC motor). This motor is the heart of the whole electric vehicles. BLDC motor control is the main control of inverter, the commutation which is achieved to control the order of conduction on th inverter arm bridge[1].

If BLDC motor to get control, we must know the rotor location, thus it can determine the commutation. Hall Effect sensor are the sensors are the sensors which are used commonly for predict the rotor position. The

voltage vector of BLDC motor is divided in six parts, which is just a one-to-one association with hall signal in six states.

### 2.4 Switching Model Of The Regenerative Braking

As shown in figure 4 the drive circuit of BLDC motor which is us in electric vehicles.

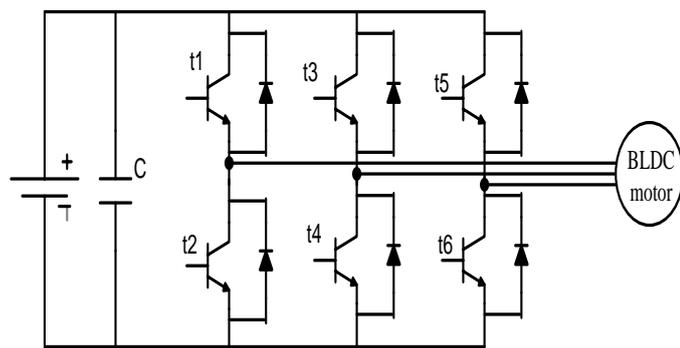


Fig-4: Drive circuit of brushless DC motor.

The process of regenerative braking is shown by the arm under the IGBT bridge whose switched movements are correspondence to the working module of the motor[6].

#### 2.4.1 Switching modification and control scheme.

The figure 5A shows the driving mode of electric vehicles. The armature current flows through the positive side to negative side of source battery. The diode is linked in parallel with every MOSFETs. Those diode can be used as freewheeling diode such for that PWM can be useful to switch devices, thus the efficiency of sytem is perfect.

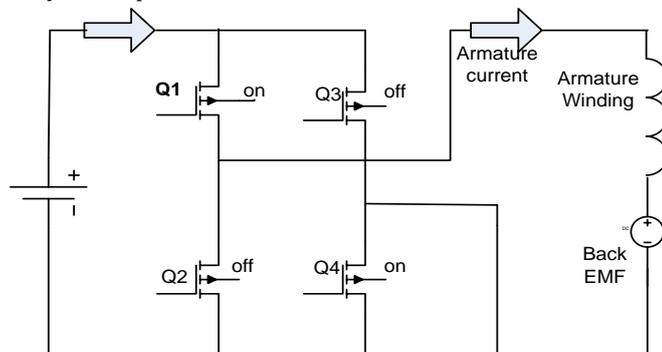


Fig-5:A. Driving mode

When we apply brakes to the vehicles, when it is in motion the system switches to braking mode. The braking mode is converted in two types of conduct stages. During first stage of brake the back emf and battery which goes in series. In this type Q2, Q3 are switched on and Q1,Q4 are switched off, so as to change the direction of armature current easily.

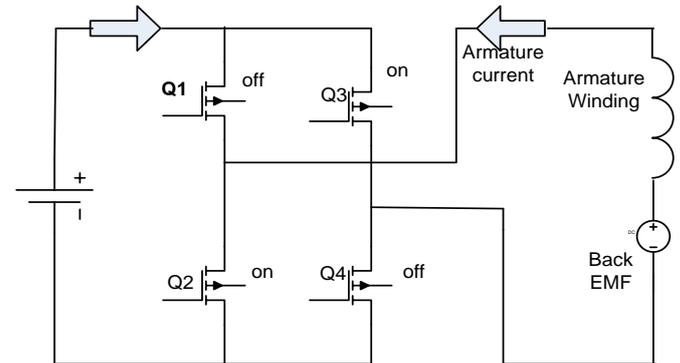


Fig-5:B. Initial Braking mode

To change the direction of armature current, in first stage of initial braking mode the back-emf and the battery goes in the series connections as shown in figure 5b. In this mode of initial braking, Q2 and Q3 are switched on and Q1 and Q4 are switched off so that armature current can change its direction automatically. When armature current increases and changes the direction itself, the state of MOSFETs will come to back automatically to its position as shown in figure 5c and battery will get charged automatically. This is how regenerative braking get implemented [3].

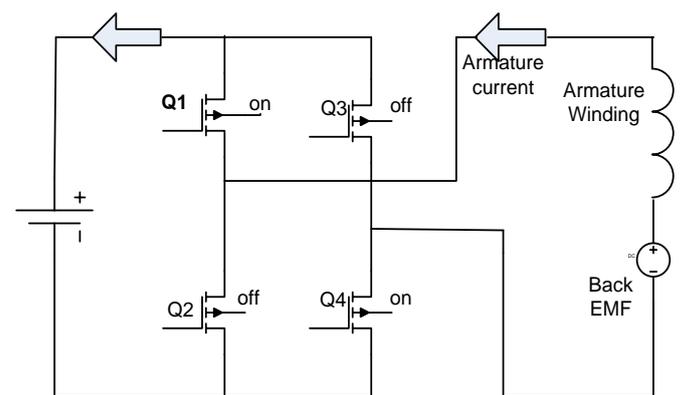


Fig-5:C. Regenerative Braking mode.

### 3. ENERGY STORAGE SYSTEM

The storage capacity of energy are more relevant in new technologies, mainly focused on ultra

capacitor, batteries and converter needed to connect power system in electric vehicles. There are so many type of batteries such as lead-acid, nickel-cadmium, nickel metal hydride, nickel-zinc, etc. To use battery correctly and properly so that system cannot be damaged, thus a basic comparative study is shown in table 1 so that we can characterize properly.

**Table-1:** Energy density, cycle life and operating temperature of batteries.

Battery type	Energy Density ( Wh/kg)	Cycle life number of cycles)	Operating Range Temperature (°C)
Lead acid battery	30-50	400-1200	20 <sup>o</sup> a 60 <sup>o</sup>
Ni-Cd	45-80	2000	40 <sup>o</sup> a 60 <sup>o</sup>
Ni-Zn	60-85	1000	20 <sup>o</sup> a 60 <sup>o</sup>
Ion-Li	110-160	500-1000	20 <sup>o</sup> a 60 <sup>o</sup>
Li- polymer	100-130	3000-4000	0 <sup>o</sup> a 60 <sup>o</sup>

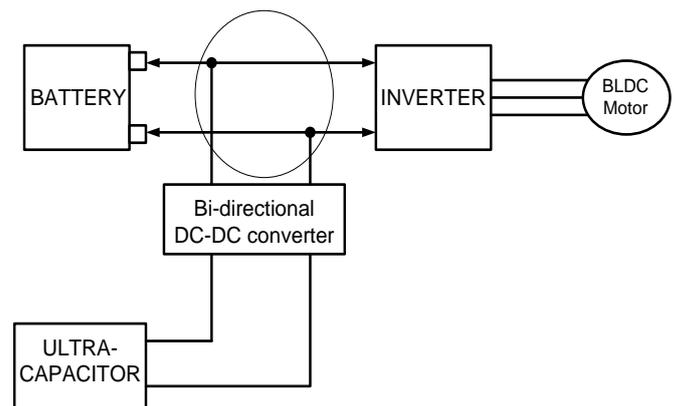
Ultra capacitor is the main technology which is based on electrochemical double layer capacitor. The main advantage of ultra capacitor is those ultra capacitors present a higher cycle life and their capacity to capture energy peaks, due to their fast response, as compared with batteries. If we use any ultra capacitor and batteries which is installed in the system, need a power converter which converts the output energy into required proper level.

The system will work flexible, when multiple batteries are installed each and every battery has its separate converter. The system will be so expensive. Hence on the other hand if we use multiple batteries which can be connected through one and only one converter. A set of small batteries and ultracapacitor working in a coordinated manner which is totally equivalent to a pack of bigger battery or ultracapacitor of the same and total energy rating.

If a large no of battery and ultracapacitor are used as mentioned above with one and as required converters are used, then both investment costs and system flexibility are reduced. The battery used in this model is lithium ion battery.

#### 4. MAIN USE OF ULTRA CAPACITOR.

Ultra capacitor plays a very essential role in the whole system, so that the new technologies have the such abilities to control them. In the ultra capacitor system, the important contents are the DC-DC converter based on the insulated gate bipolar transistor [IGBT], smoothing aluminum inductor Ls, ultra capacitor and battery pack. During acceleration, the capacitor voltage of ultra capacitor permitted to set free from packed rate charge to one-third of its nominal voltage. During deceleration, the energy of capacitor which is released during acceleration period is improved back and charge up the ultra capacitor. Ultra- capacitor is mainly used because it stores up 20 times more energy as evaluated to electrolytic capacitor as shown in figure 6. Ultra capacitor also improves the transient performance in EVs, also increases the lifespan of batteries. Ultra capacitor provides additional supply to the electric vehicles and also extends the distance.



**Fig-6.** Use of ultra capacitor in system

#### 5. PROPOSED WORK

The system and block diagram of regenerative braking is shown in figure 7. The Matlab simulation of electric vehicle consists of various blocks. In this system battery and ultra capacitor is connected in parallel as shown in figure 7.

Firstly the vehicle is going on a straight roadway if any obstacle is occurred in the middle, then driver applies brakes and that some of the kinetic energy produced is stored in the battery in the form of electrolytic charge in the batteries and the remaining charge in the ultra capacitor. To control this a dc-dc controller is designed, the controller decides that battery is full of charge and then, the charge is supplied to capacitor. The controller is a DC-DC converter, which works as a buck-boost converter. The boost operation is used for acceleration while buck

operation is use for deceleration which will help in charging capacitor.

The Matlab model shown in figure 8, the simulation of regenerative braking in electric vehicles which works on battery. The battery used is lithium-ion battery.

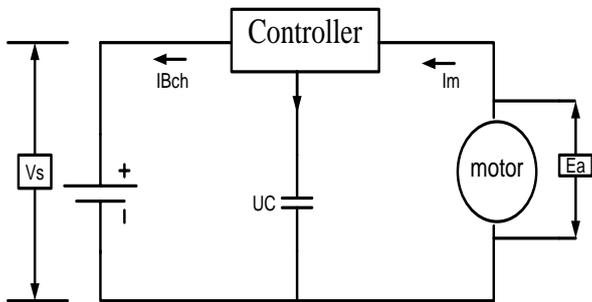


Fig-7. Block diagram of regenerative braking concept.

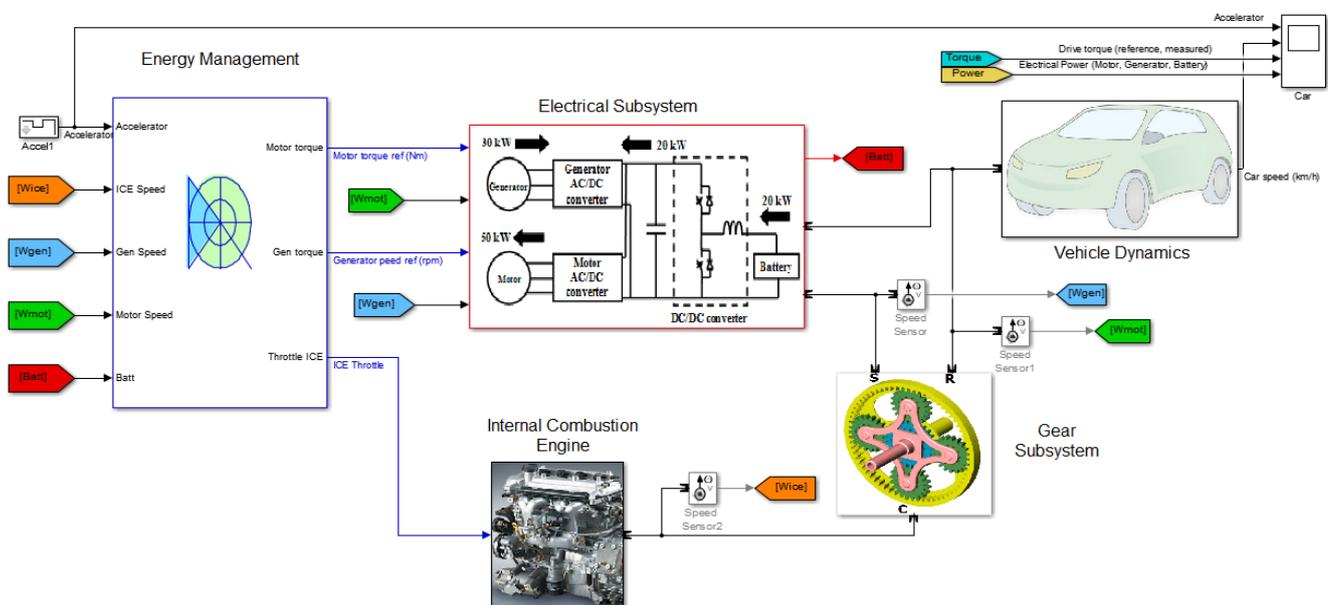


Fig:8. Model simulation of regenerative braking in Matlab.

### 6.RESULTS

The results of above model of regenerative braking are shown in below figure.

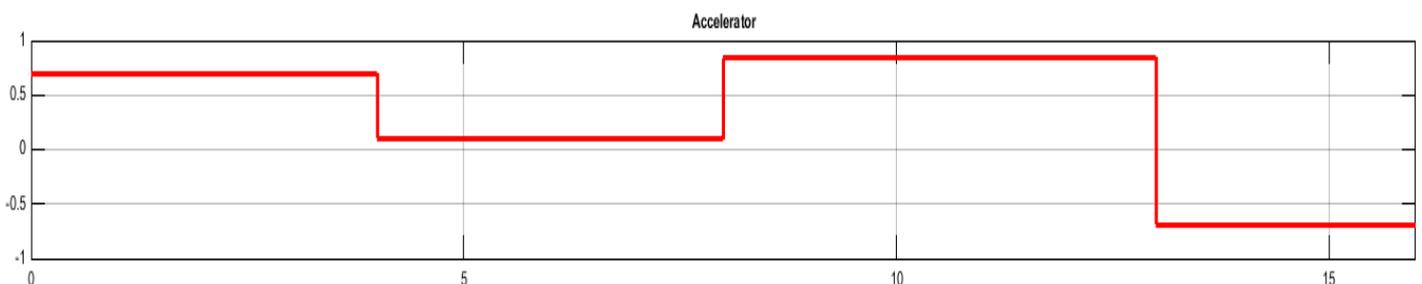


Fig-9:a. Acceleration of vehicle.

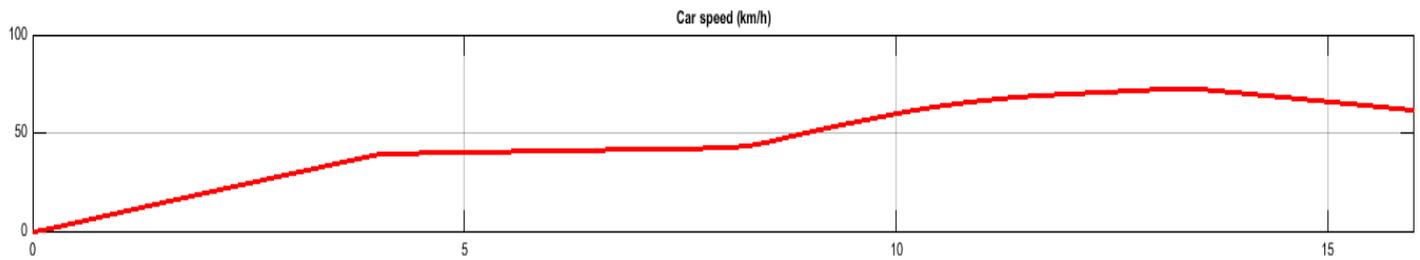


Fig-9:b. Car speed of vehicle.

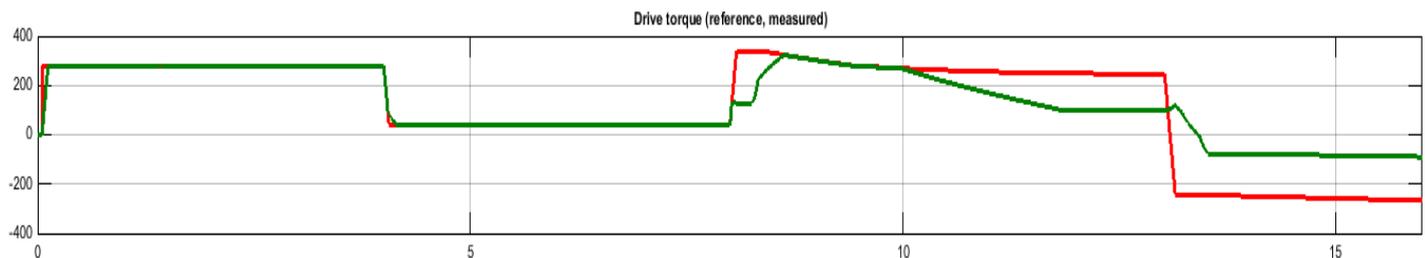


Fig-9:c. Driven torque by vehicles.

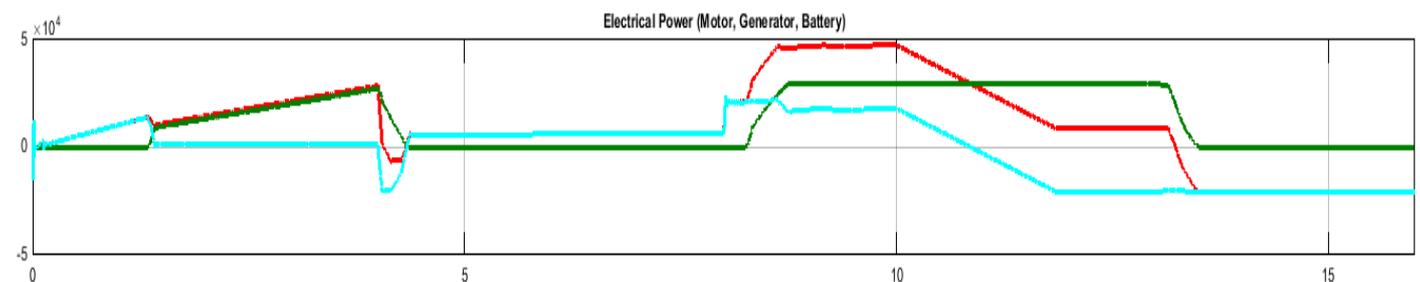


Fig-9:d. Electrical power generated by motor, generator and battery.

The above graph is the acceleration of vehicle which is done manually and when acceleration is given speed increases as shown in figure 9. The driven torque is measured from the acceleration and speed calculated. The electrical power which is calculated from whole system. The figure a shows that when we apply acceleration, speed increases as speed increases, both drive torque increases (reference torque and measured torque) as shown in figure c. As per figure d indicates motor, generator and batteries electric power.

## 7. CONCLUSION

The regenerative braking is one of the important system in electric vehicles generation. The regenerative braking has the ability to save the waste energy up to 8-25% . The regenerative braking system improved by the advanced technologies of power electronic components, are ultra capacitor, DC-DC converter. The research says that regenerative braking is already in used in many Electric Vehicles. Due to the petrol price increase gives rise to research and progress in energy conservation. It also improves the fuel consumption by 33%.

The results say that the torque driven by the vehicles is measured. Electrical power generated by motor, generator and battery is very useful and hence it should be used in electric vehicles.

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