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Novel Hybrid Two Wheeler Incorporting Regenerative Braking for Better SOC

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ABSTRACT: Internal Combustion Engine (ICE) vehicles cause severe atmospheric pollutions due to the emission of carbogenic compounds and other greenhouse gases. A 100cc two wheeler emits around 112 gram of CO_2 per kilometre. Under this situation the government has encouraged manufacturing of electric or hybrid vehicles. The complete transformation from conventional vehicle to Electric Vehicle (EV) requires a huge increase in electricity consumption and charging process is time consuming. The hybrid vehicle consists of two sources of energy, conventional IC engine and electric motor. A regenerative braking system is incorporated in the vehicle, so that the energy developed in the motor during deceleration can be utilized for charging the battery. For the efficient recovery of this energy a Super Capacitor (SC) bank is used. The stored energy in SC bank is then utilized for charging the battery. With this, periodic charging of the battery can be avoided and State Of Charge (SOC) of the battery can be maintained by the self generated energy in the vehicle. This regenerative braking will improve the efficiency of the vehicle from 16% to 70%. So with this method a vehicle which has a maximum operating range of 50Km could be extended up to 85Km. The better operating range and reduced amount of CO_2 emission of around 66 grams per kilometre is an added advantage. Simulations validating the conclusions are presented.

KEYWORDS: Hybrid Electric Vehicle, Regenerative braking, Super capacitor, Battery SOC

I. INTRODUCTION

Electric Vehicles (EVs) have been around since the inception of the automobiles. But the Internal Combustion Engines (ICE) turned out to be the most suitable for automobiles due to availability of cheap fuel, high energy density of gasoline, robust design, longer driving range, no battery charging requirements and suitable acceleration performance. Over a period, due to rising fuel costs, shortage of fuel and the pressure to reduce the air pollution, Electric Vehicles (EVs) which appear to be a clean and green alternative to IC engines came up. Major advantages of EVs are they are energy efficient, environment friendly, offer better performance, reduced dependency on fossil fuels, balanced weight distribution, less maintenance, less operating cost, less noise and vibrations. [1, 2]
But there are a few disadvantages as well, such as limited driving range per charge due to limited energy storage capacity, longer recharge time, high initial battery cost, high battery maintenance/ replacement cost, bulky and heavy weight as compared to gasoline vehicles. [2] The disadvantages of an EV and an engine powered vehicle can be compensated by using a Hybrid Electric Vehicle (HEV) The HEV is an EV at the same time engine powered vehicle. This will improve the drive range of the vehicle, as the vehicle can be driven using the stored fuel with less pollution, as engine usage is getting minimized. Rapid acceleration and high torque at low speeds can also be attained because of electric motors driven from the battery. Hence HEVs are getting more importance in the field of transportation than electric and conventional vehicles.[3]

1.1 REVAILING PROBLEMS

Only a small percentage of people are using electric or hybrid vehicles due to the reasonof lack of charging stations. Government of India has introduced various plans for the promotion of EVs and HVs. [4,9] The lack of electric energy is the main restriction for the development of charging stations in our country. This problem can be mitigated by using regenerative energy recovery scheme.

II. CHARGING INFRASTRUCTURE IN INDIA

Plans to provide solar powered charging points at the existing fuel stations of the country are on progress. [5,6,7] Cost and lack of renewable energy and grid infrastructure are the major limitations. The cost of EVs is very high mainly due to the cost of Li-ion cells. Most EVs in India provide a range of 110 Km and cost between Rs 6-8 lakhs which doesn't give any cost advantage compared to higher range cars in the same price range.The technical issues in adding renewable energy to grid infrastructureare power quality, power fluctuation, storage, protection issues optimal placement of renewable energy systems and the non-technical issues are lack of technical skilled man power, less availability of transmission line to accommodate renewable energy sources. [8]
To overcome the problems related to charging of EVs in a sustainable manner the use of HEVs instead of purely electric is proposed. It will balance the use of both gasoline and electric energy. The regenerative braking mechanism is another solution by which the energy can be retrieved from the vehicle itself. In this paper a hybrid vehicle with regenerative braking mechanism is proposed.

Table 1: Types of charging stations

Charger type	Charge connectors	Rated voltage (V)	Number of Charging Point/ Connector guns (CG)
Fast	CCS (min 50kW)	200-1000	1/1CG
	CHAdeMOminkW)	200-1000	1/1CG
	Type-2 AC(min 22kW)	380-480	1/1CG
Slow/ Moderate	Bharat DC-001(15kW)	72-200	1/1CG
	BharatAC-001 (10kW)	230	3/3 CG ,3.3 kW each

III. HYBRID ELECTRIC VEHICLES (HEVs)

A petroleum electric hybrid most commonly uses ICE (using a variety of fuels, generally gasoline or diesel engines) and electric motor to power the vehicle. The energy is stored in the fuel of the ICE and an electric battery set. There are many types of petroleum electric hybrid driven trains, from full hybrid to small hybrid,. [9, 10]

1.3.1Regenerative Braking

Regenerative braking system is an energy recovery mechanism which is used to slow down a vehicle or object by converting its Kinetic Energy (KE) into a form which can be either used immediately or stored until needed. In a nutshell, the electric motor is using the vehicle's momentum to recover energy that would be otherwise lost to the brake discs as heat. This contrasts with conventional braking systems, where the excess KE is converted to unwanted and wasted heat by friction in the brakes, or, with dynamic brakes, where energy is recovered by using electric motors as generators but is immediately dissipated as heat in resistors. In addition , to improve the overall efficiency of the vehicle, regeneration can greatly extend the life of the braking system as its parts do not wear as quickly. The most common form of regenerative brake involves an electric motor as an electric generator. In electric railways the electricity generated is fed back into the supply system. In battery electric and HEVs, the energy is stored chemically in a battery, electrically in a bank of capacitors, or mechanically in a rotating flywheel. Hybrid vehicles use hydraulic motors to store energy in the form of compressed air. In a Fuel Cell (FC) powered vehicle, the electric energy generated by the motor is used to break waste water down into oxygen, and hydrogen which goes back into the FC for later reuse. [11, 12]

IV. APPLICATION OF REGENERATIVE BRAKING

1.4.1 Electric four wheeler vehicles

Braking is one of the important aspects of a vehicle. The mechanical braking system which we use in our vehicles has a big drawback of wasting the KE of the vehicle as heat. This brings down the overall efficiency of the vehicle by affecting the fuel economy. In the urban drive cycle, chances to start and stop the vehicle is more often when compared to highway drive cycle. As the brake applies often in an urban drive cycle, the energy loss is more. Engineers came up with the regenerative braking system to recover the KE dissipated as heat during braking in the traditional braking method. Going by the laws of physics, we cannot recover the KE fully but still significant amount of KE can be converted and stored in battery or SC. The energy recovered helps in improving the fuel economy in conventional vehicles and helps in extending the range in EVs. [13]

1.4.2. Locomotives

A conventional electric train braking system uses dynamic braking, where the KE of the train is dissipated as waste, mainly in the form of heat. When regenerative braking is employed, the current in the electric motors is reversed, slowing down the train. At the same time, the electro motors generate electricity to be returned to the power distribution system. This generated electricity can be used to power other trains within the network or can be used to offset power demands of other loads such as lighting in stations. However, the power recovered via regenerative braking can only be used if that power is simultaneously being drawn somewhere else. Generally no power is recovered when the overhead power is out. [15]

V. ADVANTAGES OF REGENERATIVE BRAKING

Regenerative braking is preferred in HEVs due to the following advantages

1. It improves the fuel economy of the vehicle. [**16]**

The amount of fuel consumed can be dramatically reduced with this type of braking system. The International Journal of Vehicle Design noted in 2011 says that fuel consumption covering the NEDC (New European Driving Cycle) was improved by 25%.

2. It allows for traditional friction basedbrakes. [**16]**

A friction braking system is included with a regenerative system to ensure that the vehicle can be stopped in time.

3.Itprolongschargeofthebattery

Once the energy is captured by the regenerative brakes, the energy is used torecharge thebatteries of thevehicle. Because this energy would normally be lost, it allows each vehicle to experience a prolonged charge while driving. [16]

4. It reduces the wear and tear on the braking system. [16]

Because an electric drive train is part of this system, the greater efficiency given to the braking allows for a reduced level of wear on the brakes of the vehicle. With standard friction brakes, there is no way to accomplish this benefit.

VI. LIMITATIONS OF REGENERATIVE BRAKING [17, 18]

Regenerative braking is not by itself sufficient as the sole means of safely bringing a vehicle to a standstill, or slowing it as required, so it must be used in conjunction with another braking system such as friction based braking. The regenerative braking effect drops off at lower speeds, and cannot bring a vehicle to a complete halt reasonably quickly with current technology. Current regenerative brakes do not immobilize a stationary vehicle; physical locking is required, for example to prevent vehicles from rolling down hills. Many road vehicles with regenerative braking do not have driven motors on all wheels as in a two-wheel drive car.Regenerative braking is normally applicable to wheels

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with motors. For safety, the ability to brake all wheels is required. The regenerative braking effect available is limited, and mechanical braking is still necessary for substantial speed reductions, to bring a vehicle to a stop, or to hold a vehicle at a standstill.

VII. PROPOSED TWO WHEELER

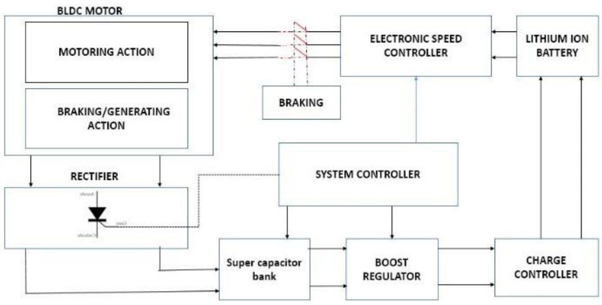

Fig1 Block Diagram of the proposed two wheeler

In the proposed system shown in Fig1 a wheel hub BLDC motor is used. The BLDC motor is controlled by using an electronic speed controller with the Li-ion battery as its power source. Whenever the braking of the vehicle occurs, the motor will act as a generator by the regenerative mechanism. The generated energy is given to a SC bank and will store the energy efficiently and act as an auxiliary storage device. This stored energy in the SC bank is further used for the charging of the Li-ion battery. A booster and charge controller is placed in between the SC bank and the battery, and the booster will step up the voltage level required by the charging circuit and the charge controller is placed to avoid the overcharging of the battery. A system controller is a microcontroller which will control all the actions taking place in the system and monitors the voltage level in the battery and SC and takes decisions. [2, 3, 5, 23]

1.7.1Components Required

1. SUPERCAPACITOR- stores large amount of energy and offers features such as high power density, long life-cycle, and wide temperature range. SCs are used in applications requiring many rapid charge/discharge cycles rather than long term compact energy storage: within cars, buses, trains, cranes and elevators, where they are used for regenerative braking, short term energy storage or burst-mode power delivery. [18, 21]

2.BLDC MOTOR- produces alternating current to drive each phase of the motor via a closed loop controller. [19]

3. ELECTRONIC SPEED CONTROLLER(ESC) - controls and regulates the speed of an electric motor. It also provides reversing of the motor and dynamic braking. EVs also have systems to control the speed of their drive motors. [19]

4. LITHIUM-ION BATTERY-Li-ion rechargeable batteries are preferred for EVs. [20]

5.CHARGE CONTROLLER- limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may protect against overvoltage.

VIII. DESIGN PARAMETERS

Initially the parameters such as speed, torque and the power rating of the motor are decided based on expected vehicle performance. The design is started by fixing the speed of the motor in running condition, and revolution per minute (RPM) is calculated. The power rating of the motor is decided from the average torque requirement of the vehicle.

1.8.1 Calculation ofrpm of Motor

The rpm of the motor is calculated from the diameter of the wheel and the maximum speed required by the vehicle.

The diameter of the wheel (D) = 0.35 meter.

The perimeter of the wheel = π*D= 3.14*0.35= 1.1 meter.

The maximum speed by the vehicle = 60km/h =1000m/min

Then the rpm is 1000/1.1~ = 1000rpm

1.8.2 Power Rating of BLDC Motor

While considering the engine parameters the average of torque required for a two wheeler = 8Nm

Then power of the motor is

$P=\frac{2\pi NT}{60A}$, Where, N = 1000rpm, T = 8Nm = =937w

1.8.3Battery Power

Peak power rating of the motor is = 900*2=1800 watts

For a 48 V battery the peak current rating will be =1800/48=37.5A, and rated current = 900/48~=20 A

To meet this, a 48 V, 40Ah Li-ion battery is selected.

1.8.4 Energy of Super Capacitor Bank

The voltage rating of each super capacitor is 2.7 volts, and capacitance of 500F. The capacitor is connected in series to get a total voltage of24V. For that 9 SCs have to be connected in series to get a voltage of 24V.The maximum energy storage of the bank $= \frac{1}{2}CV^2 = \frac{1}{2} * 55.5(24)^2 = 15998$ J

IX. SIMULATION

Simulation of electric mode and engine mode operations are carried out to find out the performance enhancement , expectedto increasethe efficiency and decrease in air pollution of vehicle. Also the simulation result of combined electric mode and engine mode performance of the vehicles are also verified while accelerating.

1.9.1 Electric mode of Hybrid Two Wheeler

At the first stage the simulation is initialized with the electric mode of operation of hybrid two wheeler. The simulation of electric mode is divided into three stages: electric driving, electric braking and battery charging.The MATLAB version 2018a is selected for the simulation of hybrid two wheeler .

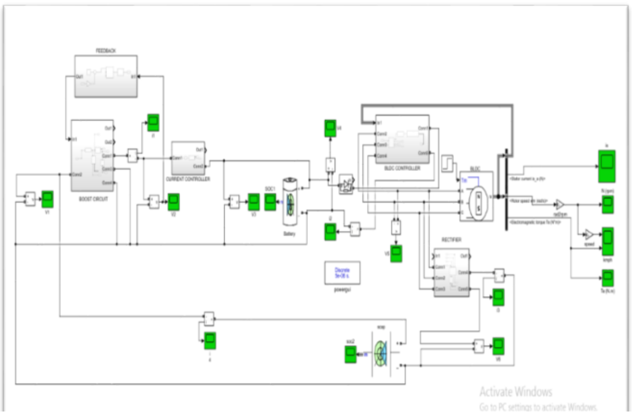

Fig.3Electric mode of simulation of hybrid two wheeler

1.9.2 Simulation-Vehicle in electric mode

For conducting the simulation of electricvehicle runningin electric mode ,for a 100kg two wheeler with passenger, the design parameters are same as in section 1.8.1. The SOC of battery is set as 100 % and the load torque is taken as8Nm, accelerating from zero speed. The simulation is conducted for a time period of 30 seconds after the vehicle is accelerated from zero speed. The simulation takes a running time of 600 seconds.

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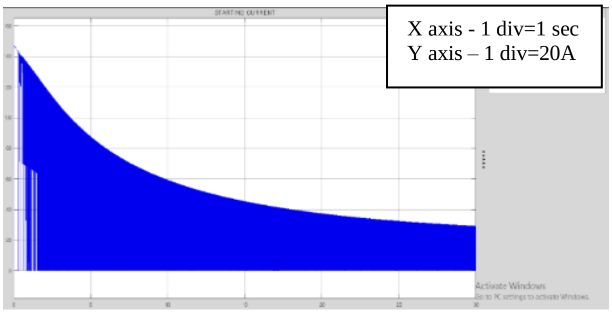

Fig. 4 starting current vs time

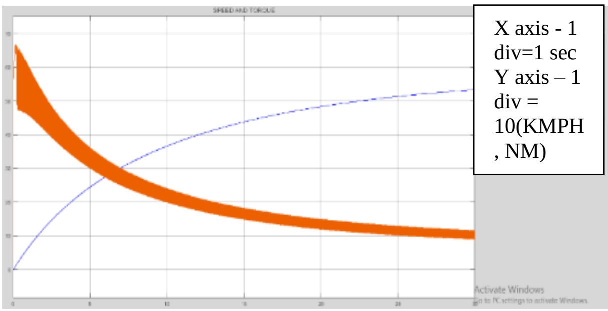

Fig.5 Battery SOC vs time

The rated current of given BLDC motor is 20 A and peak load current of 40 A, but the starting current goes around 147 Ampere, due to the inertia of vehicle as shown in Fig 4. The BLDC motors and controllers are to be designed to carry such high starting current for improved acceleration. The starting current of motor is decreased to rated current after the motor attains its rated speed of 900 rpm.The battery voltage for a fully charged 48V Li-ion battery is 56 volts. Due to the heavy starting current, for a 40A battery, the battery terminal voltage is decreased to 54 volts in 30 seconds of driving and the SOC of battery is decreased to 99.1% as Fig 5. Now the starting current decreases from 147 A to 40 A.

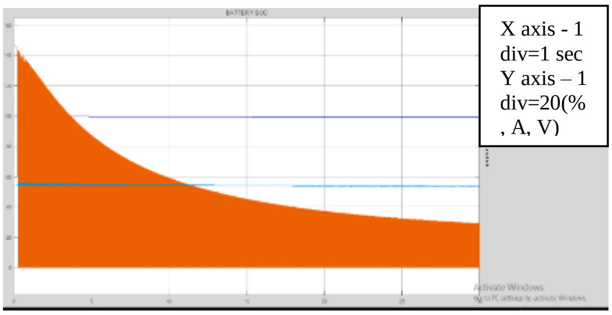

Fig 6. Rpm of motor vs time

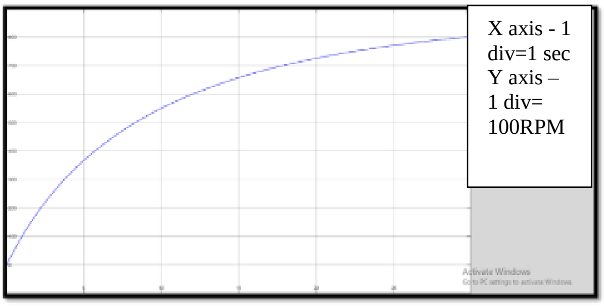

Fig.7 Speed Vs Torque

The rpm of BLDC motor is increased from zero to 800 rpm in 30 seconds.It requires few more seconds to reach its rated speed of 900 rpm as shown in Fig 6.The initial value of electromagnetic torque of motor is 67 Nm due to the inertia of vehicle. By increasing the speed of motor in Km/h, the torque of motor also decreased to rated value of 8 Nm. And the vehicleattains a speed of 53 Km/h in 30 seconds and it can achieve its top speed of 60 Km/h in few seconds.

1.9.3 WITH REGENERATIVE BRAKING

The simulation with regenerative braking of the proposed model is conducted to find out the braking efficiency of the motor. In this simulation the BLDC motor is operated as a generator instead of conducting a braking in a running machine. The maximum electromagnetic torque produced by the motor to drive the vehicle is 67 Nm, by giving the magnetic load of 67 Nm in the BLDC motor. It tends to rotate as a result of given input torque to motor and it produces electricity in the stator coils. The dynamic power is used to charge the SC bank in this simulation. The specifications of SCis same as in section 1.8.1 and initial voltage of capacitor is taken as zero. A 3 phase controlled rectifier is used in the simulation for [14].

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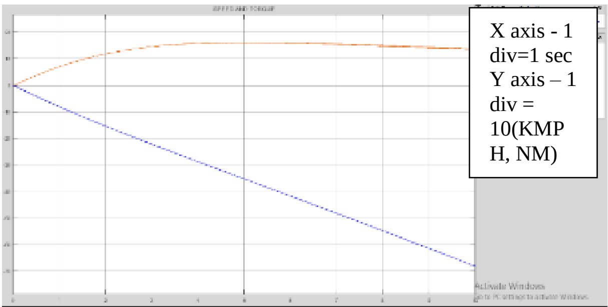

Fig 8. Speed – Torque

While braking, the supply from the battery to the motor is disconnected and the rectifier is turned ON. The simulation is conducted for a time period of 10 seconds after braking and it takes 200 seconds to run the simulation. From the speed- torque graph in Fig 8, the BLDC motor can produce braking torque of 15Nm ata speed of 60Km/h and a maximum braking torque of 18Nm in 35Km/h. When the vehicle has a rated speed of 60Km/h, vehicle takes 8.8 seconds to stop completely.

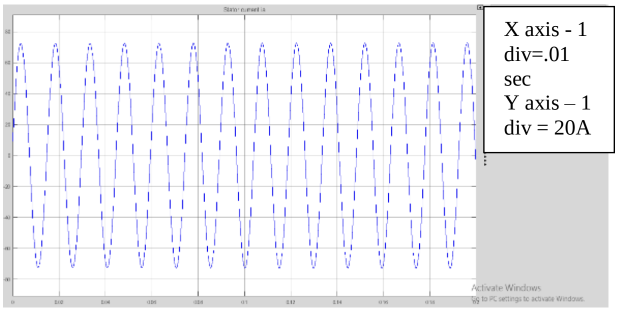

Fig.9 Stator Current vs time

While applying regenerative braking in BLDC motor the stator current is sinusoidal and it has a peak value of 72 A and RMS value of 52 A. The Supercapacitor can effectively harness this braking energy.

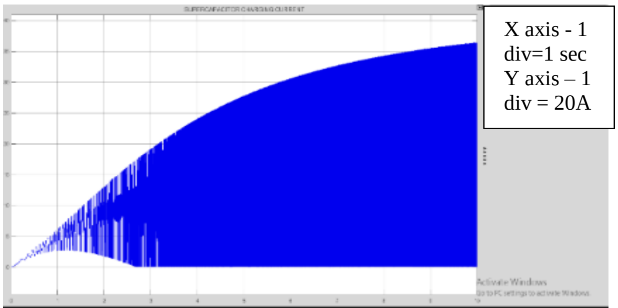

Fig.10SC Charging Current vs time

The regenerative braking gives a maximum charging current of 35 A in a rated speed of 60Km/h. The charging current is decreased with decrease in speed of vehicle. The high current density of SC gives more effective braking to the vehicle in less than 9 seconds.

The SOC of SC bank is increased with respect to the charge coming from the braking of vehicle as shown in Fig 10. The initial voltage of capacitor bank of 24.3V and 28F is zero, so that the SOC of capacitor bank is zero. The low

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Fig.11 SC SOC in Regenerative Braking vs time

SC can produce more braking torque to the motor and also the braking current. This can dynamically charge the SC bank to 3.5% of SOC in one braking. It comes around 1500 joule-second of energy.

1.9.4 SIMULATION OF CHARGING OF BATTERY FROM SUPERCAPACITOR

Since it is not a Plug-in Hybrid Electric Vehicle(PHEV) the SOC of the battery has to be maintained to maximum value by charging the battery by the energy stored in the Supercapacitor which was recovered from the regenerative braking. The capacitor bank has only the maximum voltage of 24.3 V and the battery is of 48 V, and also the terminal voltage of SC decreases linearly with the SOC of the SC. So a closed loop boost regulator with proportional integral derivative(PID) controller is used to charge the battery of 48V from 42 to 56 v range depends on the SOC of the battery. In this simulation the SOC of battery is set as 90% and the SC bank has an initial voltage of 24V. The simulation is conducted for a time period of 5 seconds and it takes 200 seconds to complete the running of simulation.

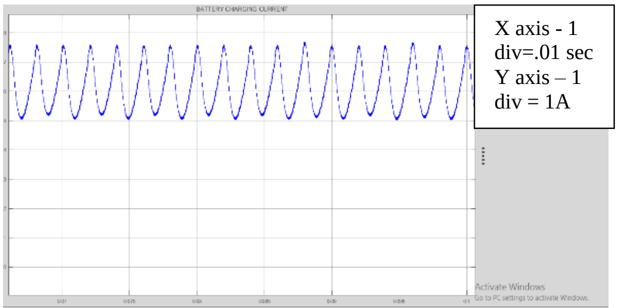

Fig.12 Charging Current vs time

By using the closed loop boost regulator the charging current of battery has an RMS value of 6.2A F. The charging current decrease with increase in the SOC and battery voltage reaches 56 V.

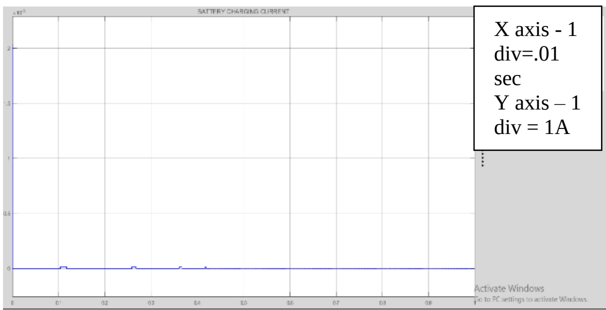

Fig.13 Charging Current vs time

In this graph the terminal voltage of battery reaches 56 volts, that means 100% SOC then the charge current of battery reaches zero ampere. Hence the overcharging of battery can be avoided using closed loop system.

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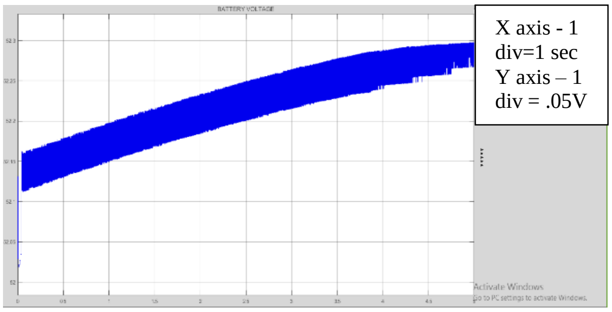

Fig. 14 Battery voltage in charging vs time

The battery voltage increases from 52.02 V to 52.23 volts in 5 seconds shown in Fig 13, it shows the battery requires few more minutes to fully charge.Supercapacitor discharging in an RMS current of 17 A to charge the battery using boost regulator. The terminal voltage and SOC of capacitor bank is decreasing with the time of charge as shown in Fig.15.

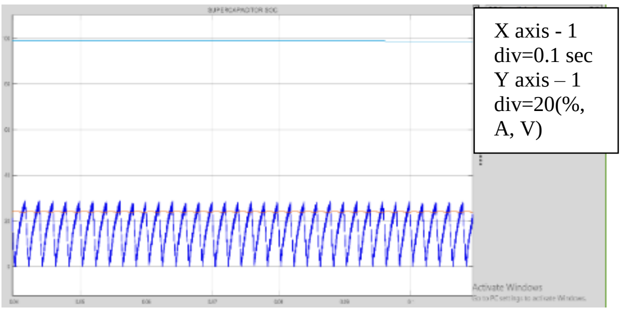

Fig.15 SC SOC While Discharging vs time

So that the Supercapacitor can maintain the SOC from the brake applying in vehicle.

X. CONCLUSION

A hybrid two wheeler with enhanced performance is proposed with regenerative braking. The government of India has decided to motivate the production and innovations of electric and hybrid vehicles as part of the National Electric Mobility Mission Plan. Comparing with an EV, a hybrid electric vehicle has the advantage that it consists an additional power source as the conventional engine, so that the vehicle can be switched to engine powered and electrically powered according to the speed requirement so that the fuel efficiency can be improved. An additional feature of regenerative braking mechanism is also included in the vehicle, which helps to recover the energy developed in the motor during braking for charging of the battery .This will reduce the need of periodic charging of the battery and increase the reliability of the vehicle. The atmospheric pollution can also be controlled up to a limit.

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