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Design, Testing and Performance Analysis of E-Bike

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Thanking you.

Darekar Dipak Samhaji
ME HEAT POWER

ABSTRACT

The main aim of this report is to present the idea of harnessing the various energy and use it in today's existence of human life. For human being travelling has become vital. In order to sustain in this fast forward world he must travel from place to place.

The electric vehicles industry is continuously evolving. One type of such electric vehicle is the electric bicycle (e-bike). Electric bicycles, like other electric vehicles, use a BLDC motor (Brushless Direct Current Motor). This report presents a way of designing and implementing an electronic module for an e-Bike. The report shows how a low power, 8-bit microcontroller can be used to drive such a motor and also manage other useful functions on an e-Bike.

INTRODUCTION

The necessary needs of an EV are reduced design effort, lower cost, less depreciation, and optimization of the volume and weight needed by the traction drive system. These necessities have led to develop a new generation of electric drives which are called multi-machine drive systems. Optimization of the weight and volume, reliable performance with less protection requirements, and low price of multi-machine systems compared to conventional systems are the reasons of usage of these systems in EVs. The rapid urbanization has also resulted in a more increase the number of motor vehicles. The vehicle fleets have even doubled in some cities in the last one few years. As the number of vehicles continues to grow and the consequent congestion increases, vehicles are now becoming the large source of air pollution. In multi-machine drive systems, controllers of the machines must create a combined system as an electric differential; in addition to control of the drive. The electric differential should be considered to calculate the difference between the EV speed in different road conditions [5].

Transportation involves the combustion of fossil fuels to create energy translated into motion. Pollution is created from incomplete carbon reactions, unburned hydrocarbons or other elements present in the fuel or air during combustion. These processes produce pollution elements of various species, including carbon monoxide, soot, various gaseous and liquid vapour hydrocarbons, oxides of sulphur and nitrogen, sulphate and nitrate particulates, ash and lead. These primary pollution elements can, in turn, react in the atmosphere to form ozone, secondary particulates, and other damaging secondary pollution elements. Combustion also creates carbon dioxide, the primary greenhouse gas. The share of fossil fuel used in the transport sector varies widely from region to region and city to city. A number of factors can be identified as influencing the amount of emissions attributable to the transport section, and an effective strategy will need to consider all these factors. They include the amount that vehicles are used in a given country or city area; the age of the vehicle fleet and the technology used within it; the extent to which vehicles are properly maintained; the availability of appropriate fuels and the extent to which they are used properly; and Atmospheric, climatological and topological conditions. Air pollution is one of the serious environmental problem of the urban areas. The health related problems such as respiratory diseases, risk of developing cancers and other serious ailments etc. due to poor air quality. Air pollution is a phenomenon by which particles (solid or Liquid) and gases contact with the environment. Such contamination can result in health effects on the population, which might be either chronic, or due accidents.

CONSTRUCTION AND OPERATING PRINCIPLE

The general BLDC motor drive is shown in Fig 3.1. Since BLDC motor is an electronically commutated machine, the switching of each phase depends on the current rotor position.

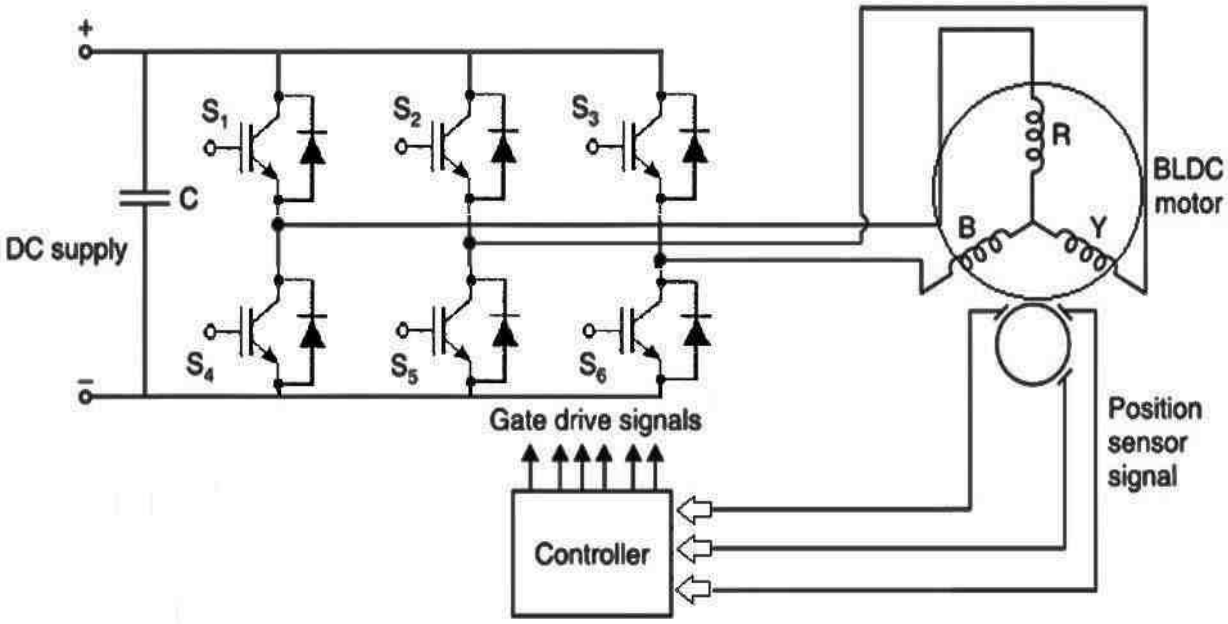

Fig. 3.1. BLDC motor drive – General schematic. [4]

This can be determined using hall sensors. Electronic commutation done by using a Voltage Source Inverter (VSI). Each switch of VSI conducts for period of 1200 and each switching pair is conducts for 600. The logic used for developing the commutation strategy can be described by equations (1), (2), and (3)

Out1 = HA – HB (1)

Out 2 = HB – HC (2)

Out 3 = HC – HA (3)

Out1, Out2, Out3 are the signals created by the hall block. This entire logic is done by the controller block and it is simulated for BLDC motor with parameters.

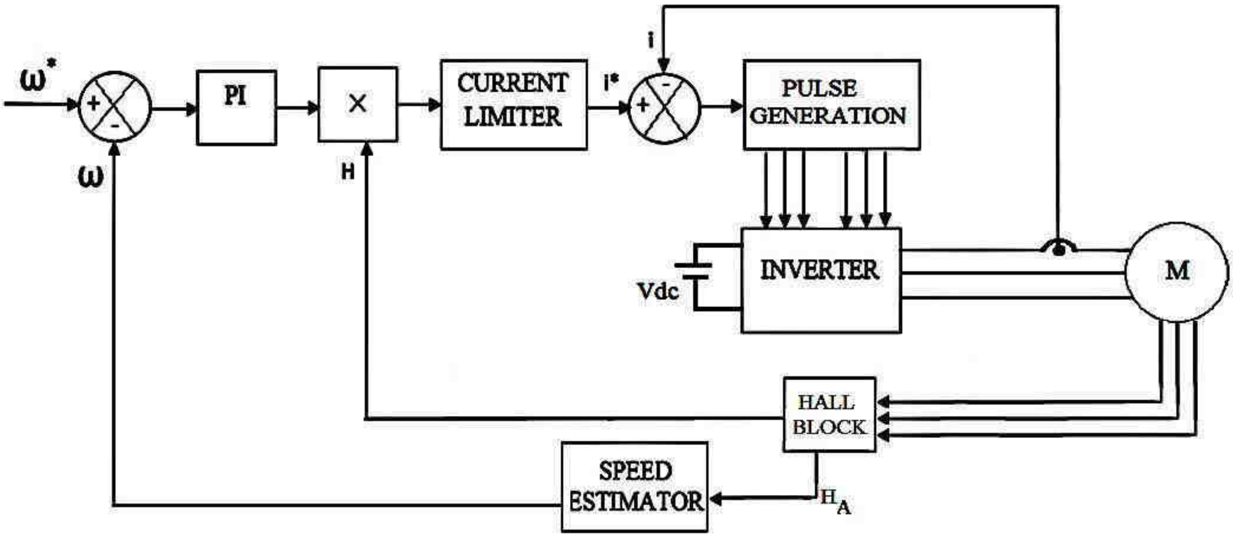

Fig.3.2 BLDC Motor Proposed Block Diagram. [4]

The closed loop speed control of BLDC motor is described in Fig. 3.2. A speed reference is set and it is compared with the real machine speed, which is estimated by using speed estimator, thus removing the need of a speed encoder. The speed error will be reduced to zero by generating a suitable current reference using a PI controller which decides the polarity of the reference current that will be positive, negative or zero. The actual stator current of the machine is measured using a current sensor. The reference and actual currents are compared and the current-error is given to a hysteresis controller. This controller generates PWM pulses so as to force the actual current obeys the band limits. These PWM pulses fed to the VSI drives the BLDC motor so that actual speed of the machine tracks the reference speed.

The structure of a BLDC motor is divided into two parts

- Moving part called the rotor, represented by permanent magnet
- Fixed part called the stator, represented by phase windings of magnetic circuit

Stator

The stator of a BLDC motor consists of stacked steel laminations with windings mounted in the slots that are axially cut along the inner side periphery. Traditionally, the stator resembles an induction motor; however, the windings are divided in a different manner. Most BLDC motors have three stator windings connected in star connection. Each winding is constructed with numerous coils that are interconnected to create a winding. One or more coils are mounted in the slots and they are interconnected to create a winding. Each winding is distributed over the stator periphery to form an even number of poles.

Rotor

The rotor is made of permanent magnet and can changes from two to eight pole pairs with alternate North (N) and South (S) poles

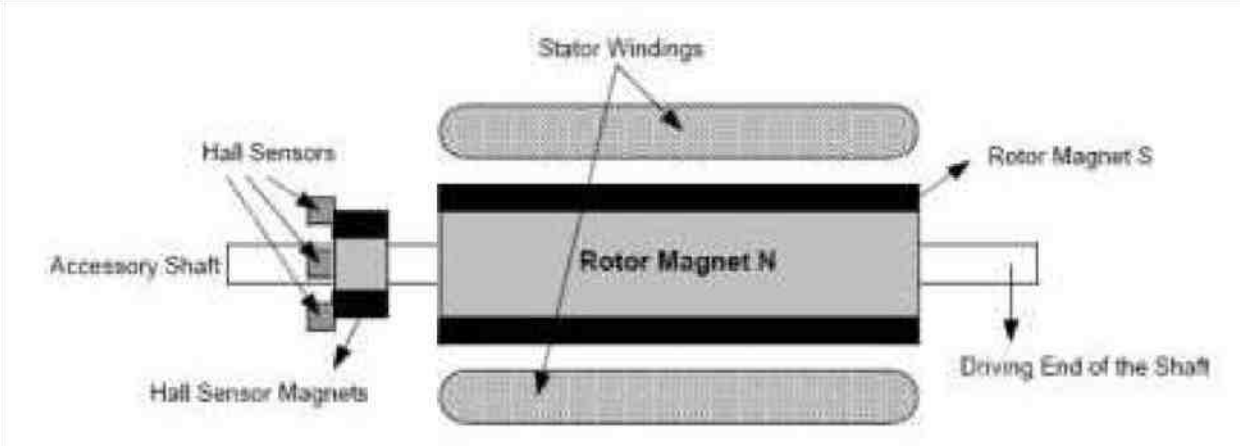

Figure 3.3: BLDC Motor Mechanical Structure

Unlike a brushed DC motor, BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a special sequence. The rotor position should be known in order to understand which winding will be energized next. The rotor position is sensed using Hall sensors that are embedded in the stator.

Most BLDC motors have three Hall sensors embedded in the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they generate a high or low signal, which indicates that N or S pole is passing near the sensors. Based on the combination of these Hall Sensor signals, the exact sequence of commutation can be determined.

Because of the increasing popularity of e-bike, motors designed specifically for e-bike applications are now commercially available. These motors vary a great deal in what manner they are mounted to a bicycle and in what manner the power is applied to them.

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E-BIKE ELECTRIC SYSTEM

4.1 Block Diagram

The block diagram of the designed electric system is presented in Fig. 4.1.2. The implementation of the proposed control unit is on the base of an 8-bit microcontroller.

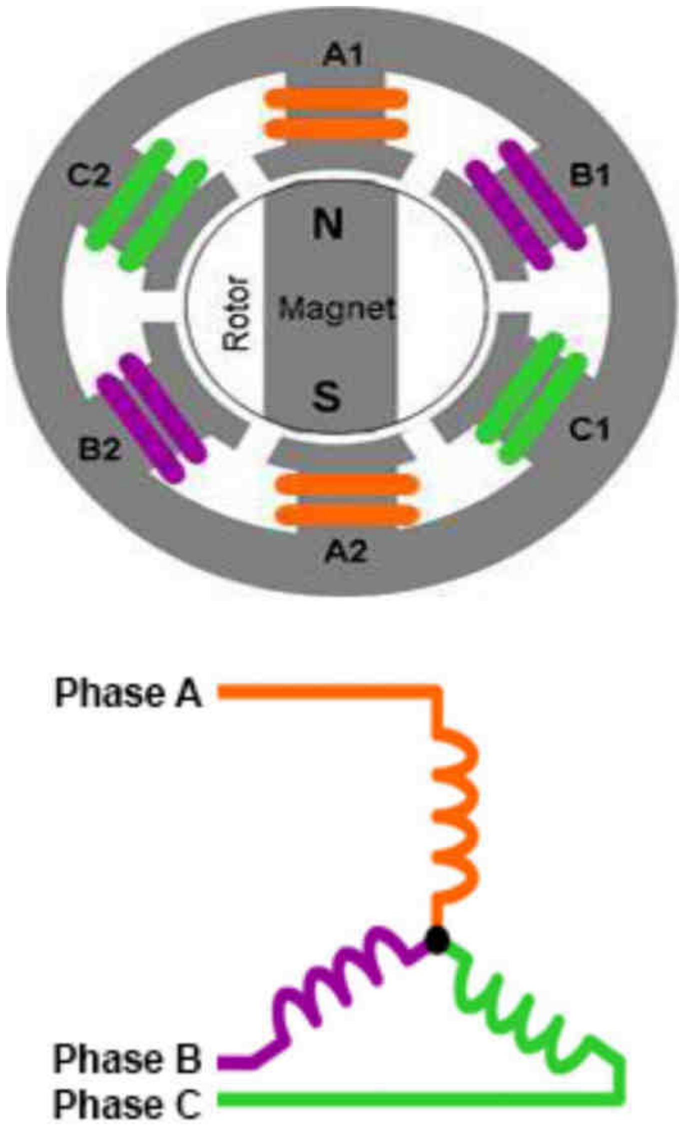

Figure 4.1.1: BLDC motor: a) simplified internal structure; b) motor windings. [9]

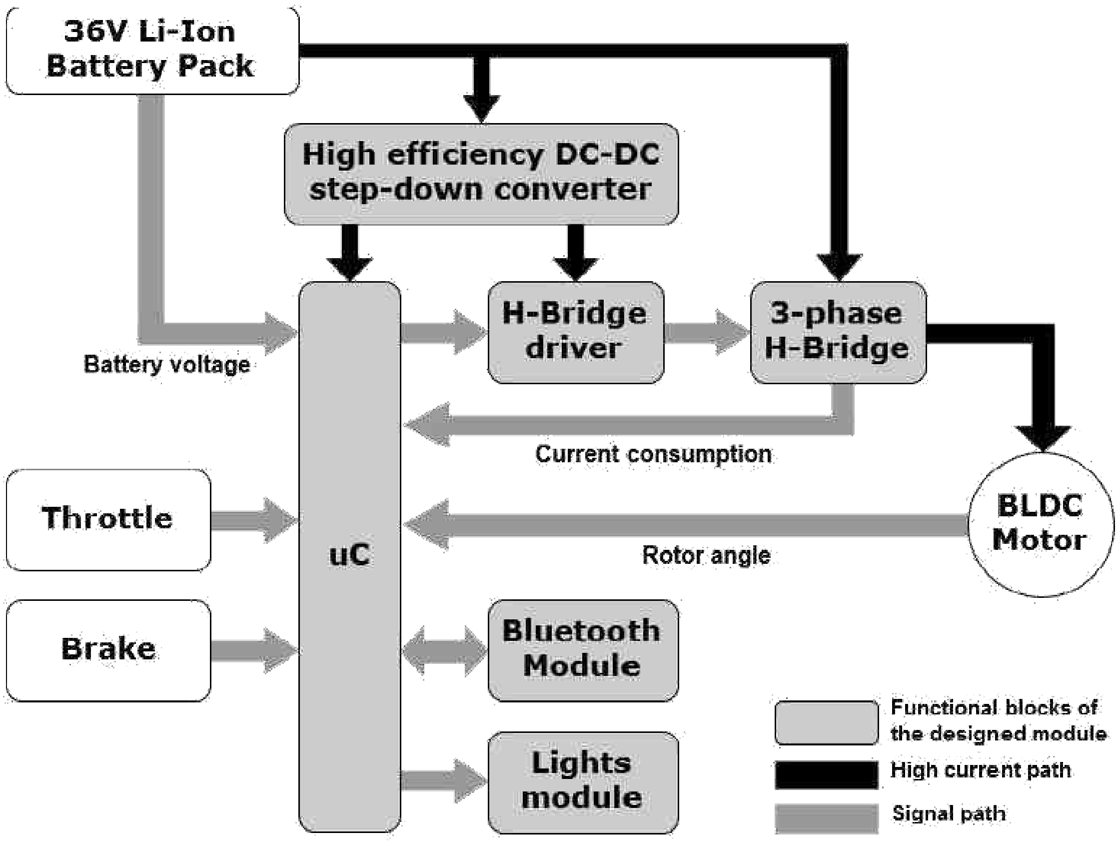

Figure 4.1.2: Block diagram of the designed e-bike electric system. [9]

The microcontroller receives information about the motor position (rotor angle), via signals sensed by three Hall sensors contained within the motor.

Using this data, the microcontroller uses a simple commutation table and switches the six power MOSFET transistors which drive the BLDC motor.

Internet-based literature (images only) tolds that BLDC controllers used in commercial e-Bikes include linear power supplies. This is a main issue regarding power efficiency, due to the significant power loss as heat in the internal power supply.

One of the improvements this design brings is the use of a DC-DC step down converter, which greatly reduces the power consumption of the module and reduces the ambient temperature in the case of the module. The latter is an important issue, considering the fact that the electronics on an e-Bike must be housed in a water-proof enclosure. The user of the e-Bike receives relevant data (e.g. instantaneous speed, battery state of charge) from the motor controller via Bluetooth protocol and can view the data on a GUI (graphical user interface

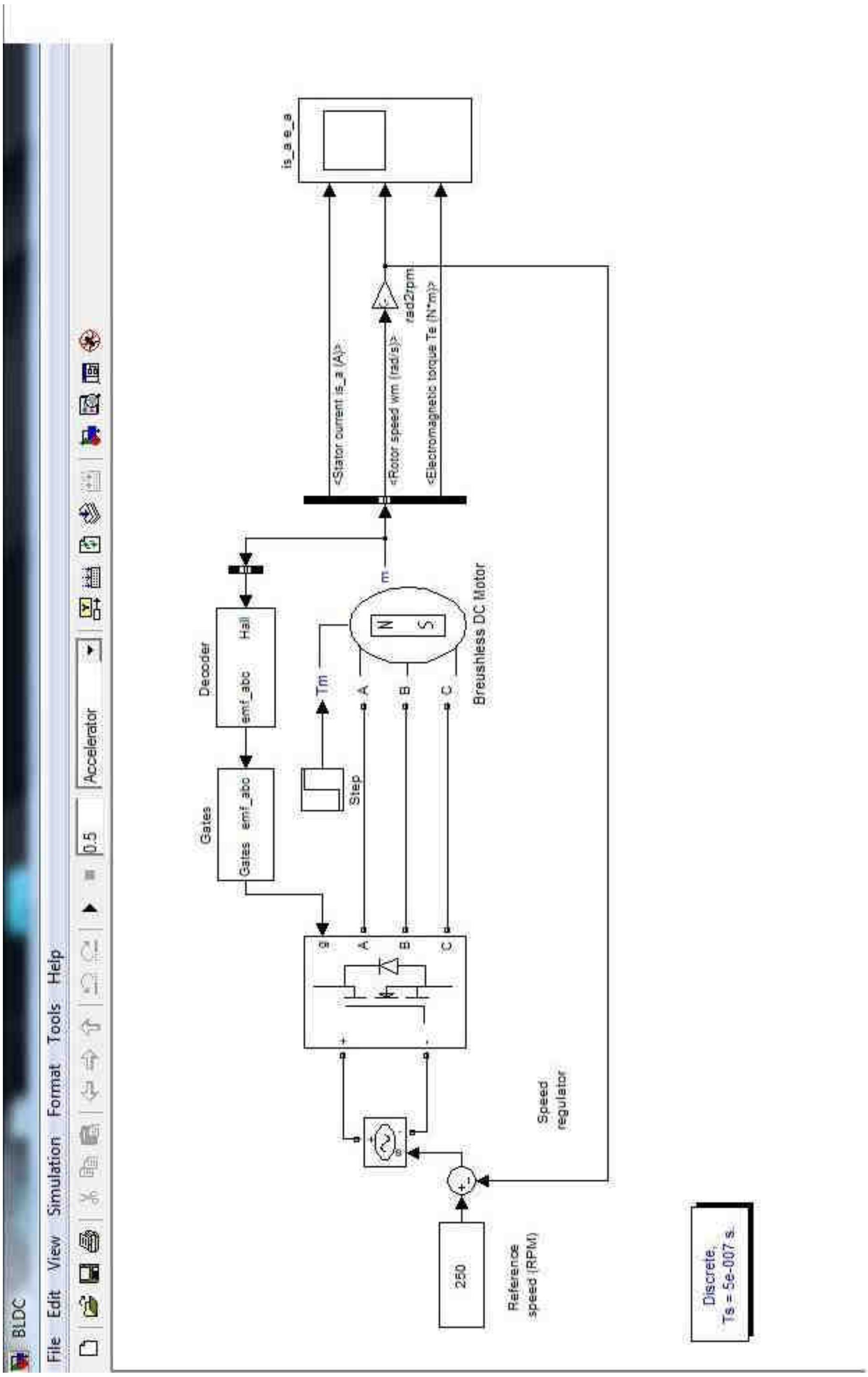

Fig 5.1.1: Simulation model of BLDC Motor

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MATLAB SIMULATION RESULTS

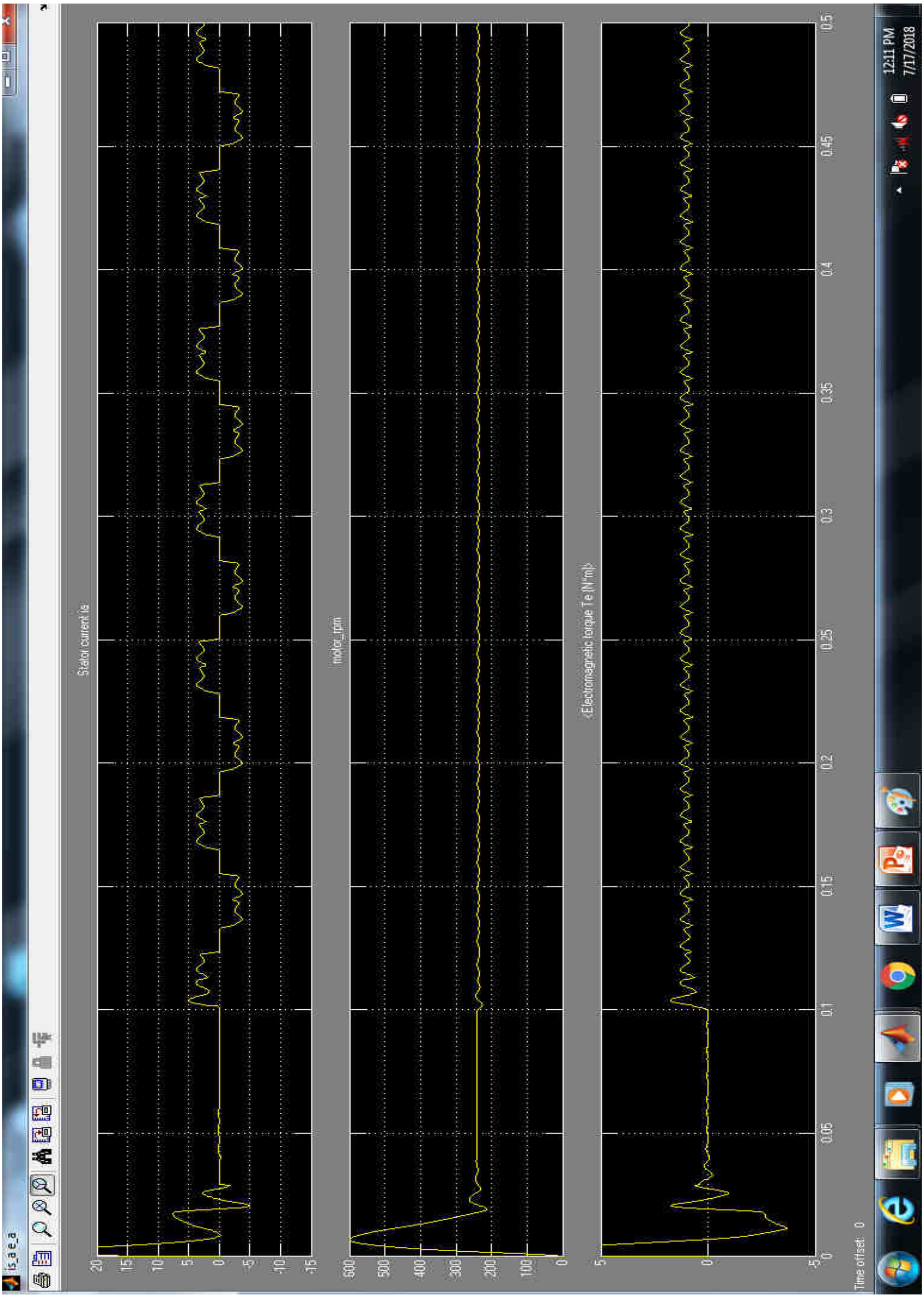

Fig:6.1 MATLAB Simulation results (Ia, Speed, Torque):

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Fig 6.2: Simulation model result for Back EMF_A

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DESIGN OF THE PROJECT HARDWARE

7.1 Design of the Project hardware

In hardware design there is a one BLDC HUB motor (250W, 36V, 250 RPM,), Conventional bicycle, motor control circuit, Battery with charger.

FIG 7.1.1: BLDC HUB MOTOR

A controller for an electric bicycle must provide power that varies from zero to the rated peak of the propulsion-motor, at motor speeds corresponding to bicycle speeds from zero to 23 km per hour. With DC propulsion motors, power can be controlled with pulse-width modulated (PWM) transistors. AC motors need changing frequency. Hardware requirements for design of an EV control are postulated and basic blocks along with their applications are shown.

An electric bicycle has a conventional bicycle frame, pedals, cranks, chain, and freewheel assembly. Electric propulsion supplements muscle power. This adds to the bicycle an electric motor, gear reducer, battery, and power control. The following defines the requirements of an electric bicycle:

- The complete bicycle must have the less practical mass. All mass must be hauled over hills with energy supplied by the battery. Lower mass gives large range between recharging of the battery.
- Bicycle stability is another one more important requirement. Total mass need not affect stability, but the placement of mass is important.

Table 1 lists the range of mass that is considered to be propelled.

7.1.1 Range of Mass

COMPONENT	MASS IN KG
Bicycle assembly	15
Motor	3
Battery & Controller	1.2
Cyclist	80
Total weight	99.2

Table 7.1.1: Range of Mass

Figure 7.1.2 shows the required power to develop the necessary wheel torque for the indicated travel conditions:

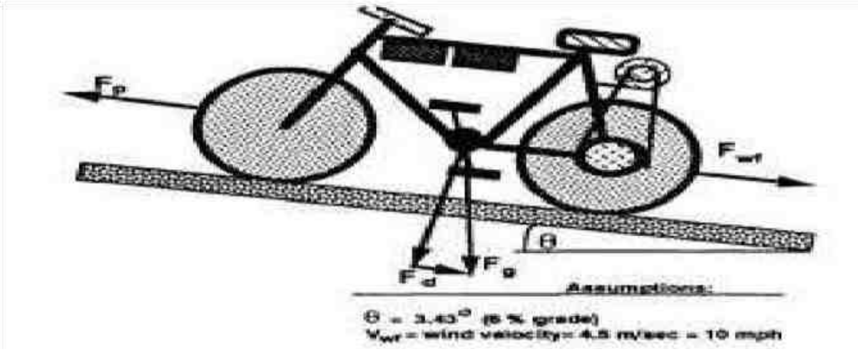

Figure 7.1.2: Range of Mass

F_{wf} = Windage and friction drag

F_d = Downhill force from gravity

F_P = Propulsion force = F_{wf} + F_d

7.1.2 Calculation of Motor Torque for E-Bike:

Assume normal bike with pedal length: 22cm i.e. 0.22m

Weight of human assume range in between 60 to 90 KG

At initial condition human have to apply more torque i.e. (weight 1Kg=9.81N)

Suppose human is applying initial force in range between (15-20 Kg) and running condition very less force

Formula for Torque:

T =F*D (Distance)

T =20*9.81*0.22

=43.16 NM (At initial)

We required 43NM Torque at initial but very less for running condition

If we consider W =15 KG

Then, **T =32 NM**

7.1.3 System Implementation:

Our prototype will follow standard HMH (Human-Motor-Hybrid) electric bicycle construction, consisting of the following main components, visible in Figure 7.1.3. The main components are:

1) BLDC Hub Motor,
2) Motor Controller,
3) Li-ion Battery,
4) Handle bar mounted digital display and half throttle with key switch,
5) Peddle & chain arrangement.

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Figure 7.1.3: Modified Electric Bicycle

7.2. Battery Selection

See the following equations to calculate the range from ampere and voltage:

Ah (Amp hours) × V (volts) = Whrs (Watt hours) (1)

Select a 36-V, 4.8-AH battery with 173 Wh.

P (power) = Work / t (time) (2)

P × t = Work = Force × distance (3)

Force = mass × acceleration (4)

Distance = Wh / Force (5)

Distance = Wh / Force (6)

Electric bicycles are often limited to a speed of 22 km/h across level ground. A larger wattage increases the range and can increase the uphill torque; however, a larger wattage does not typically increase the maximum speed which is restricted.

From the previously listed equations, a 173-Wh battery can roughly provide a range of total 22 km. based on the information a Li-ion battery is selected.

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The 36-V, 4.8 AH battery is selected with the following performance specification:

- Voltage: 36 V
- 173 Wh
- Maximum continuous discharge current: 9.3 A
- Operating temperature:-20C -60C
- Charging time: 1.5hrs

Typical Lithium Ion battery is shown in figure 7.2.1

Figure 7.2.1: Lithium Ion Battery

These batteries are high capacity battery packs specifically created for an e-Bike application. These batteries come with a light-weight (1 kg) aluminum casing and safe connector. A universal charger with the following specifications is available.

7.3 Charger specifications:

Figure 7.3.1: Battery Charger shows battery charger.

- AC input: 100 V_{AC} to 240 V_{AC} 50/60 Hz, 1.5A
- DC output: 42 V at 2 A, maximum power 84w
- DC connector size: 3 prong Inline
- Weight: 235gm + 55gm

Figure 7.3.1: Battery Charger.

7.4. Controller

There are two types of controllers designed to match either a brushed motor or brushless motor. Brushless motors are becoming more common as the price of controllers continues to decrease.

Controllers for brushless motors: E-bikes require more initial torque and therefore models that use brushless motors typically have Hall sensor commutation for speed and angle measurement. An electronic controller provides assistance as a function of the sensor inputs, the vehicle speed and the required force. The controllers generally allow input by means of Hall Effect twist grip, closed-loop speed control for precise speed regulation, protection logic for over-voltage, over-current and thermal protection. Bikes with a pedal assist function typically have a disc on the crank shaft featuring a ring of magnets coupled with a Hall sensor giving rise to a series of pulses, the frequency of which is proportional to pedaling speed. The controller uses pulse width modulation to control the power to the motor. The support is provided for regenerative braking but infrequent braking and the less mass of bicycles limit recovered energy. An implementation is described in an application note for a 250 W, 36V Brushless DC (BLDC) motor.

Controllers for brushed motors: Brushed motors are also used in e-bikes but are becoming less common due to their lower efficiency. Controllers for brushed motors however are much simpler and cheaper due to the fact they don't require hall sensor feedback and are typically designed to be open-loop controllers. Some controllers can handle multiple voltages. 48V 750W Electric Scooter Speed designed for 48 Volt DC electric scooter and bike motors up to 750 Watts. Maximum current 30 Amps. Under Voltage protection 41 Volts. Current limiting feature prevents controller and motor damage due to over-current conditions. Under voltage protection feature prevents over-discharge and extends battery life. Supportable with all standard 3- wire variable speed hall-effect throttles.

Figure 7.4.1: Controller

Specifications:

- Rated voltage: DC 36V
- Rated power: 350W / 450 W

- Over current protection,
- Automatic identification the Hall sensor
- Automatic identification the Phase angle of 60 degrees and 120 degrees
- Pedal assist,
- Power assist
- Applicable model: electric bicycle, electric scooter.

7.4.1 Controller Features

1. Gears and Efficiency

Not all electric bicycles offer many gears within the electric motor. In such cases, a single gear for the motor lowers efficiency, particularly when climbing hills. Changeable gears makes hill climbing so easier, and increases the life and performance of your motor. A single gear on a car would make good hill climbing and efficient top speeds impossible. Adding more power to the motor when climbing hills and accelerating is possible, but this is alone not an efficient approach

A single-speed gear can require you to carry heavier and possibly a more expensive battery or set of batteries. Also, overloading an electric motor makes heat, which is wasted energy that can harm electronics and motors, and reduces the life of the product. Having gears for the motor supports better performance, creates greater efficiency, and provides a large life for the product.

2. Recharging Electric Bicycles with Alternative Energy

For those who are willing to invest in this approach, solar or wind technology can support the recharging of electric bicycles. This approach can be established in one of the following ways:

- Solar design is done well enough to build a custom solar recharging station
- Invest in a solar or wind energy kit, sometimes available as a recharging station specifically built for EV.

3. Appropriate Brakes

Given the increased weight and speed of electric bicycles, conventional rim brakes likely do not supply sufficient stopping power, particularly when wet. Disk brakes last longer, require less maintenance, and work very well in wet conditions. Regenerative braking is partly available.

4. Battery and Motor Location

A low center of gravity can and will deliver superior handling, but it is not uncommon for some very popular bikes to have at least one battery (in a package of two) on a bike rack behind the seat.

5. Performance Suspension

The high speed and weight of electric bicycles create the need for suspension that exceeds that of normal bicycles. A high-quality, name-brand front and rear suspension keeps the body of the rider comfortable at more speeds and protects electronics.

7.5 COMPONENTS LIST

Sr. No	Equipment Name	Equipment Specification	Price
1.	BLDC Hub Motor	36V, 250W, 3Phase, Hall sensor, Geared Motor	9000/-
2.	Lithium Ion Battery	36V, 4.8AH, 1kg	6000/-
3.	Anti-theft controller	36V, 250W	2400/-
4.	Battery Charger	42V, 2A	1800/-
5.	Half Throttle With Key Switch	NA	900/-
6.	Second Hand Ranger Cycle	NA	1600/-

7.	Alloy Beam	NA	2150/-
8.	Tire/Tube	26”	1568/-
9.	Handel With T Bar	NA	332/-
10.	Brake Lever	NA	300/-
11.	Miscellaneous Items	NA	1665/-
	Total	**NA**	**27715/-**

Table No: 7.5.1 Components List And Costing:.

7.6 Project Image

Figure 7.6.1: E-BIKE

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Practical Results of E-BIKE

8.1 Discharging Performance at no load.

SR. NO.	SPEED (rpm/kmph)	TIME(MIN)	BATTERY VOLTAGE
1	110/13.2	10	35.4
2	150/18.0	20	35.3
3	190/22.8	30	35
4	230/27.6	40	34.9

Table no: 8.1.1: Discharging Performance at no load.

Above Table no: 8.1.1 shows Discharging Performance at no load.

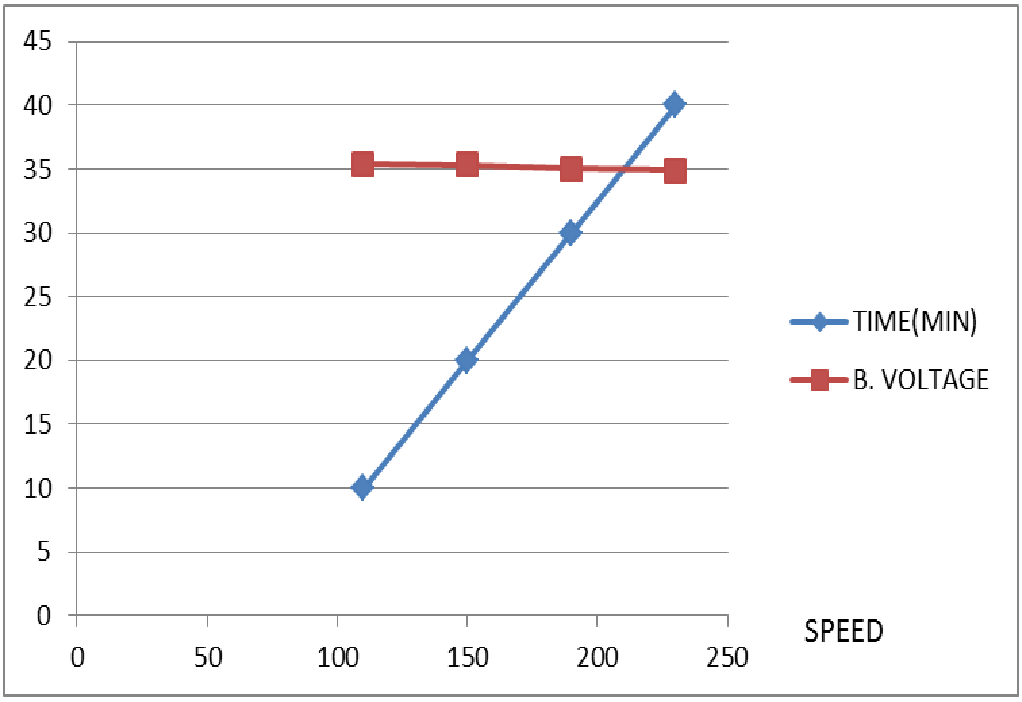

Fig:8.1.1: Graph for Battery Discharging Performance at no load

Above Fig:8.1.1shows Graph for Battery Discharging Performance at no load.

8.2: Battary Charging Performance for every 20 min.

SR NO	TIME (MIN)	BATTARY VOLTAGE	BATTARY CURRENT
1	20	35.15	1.1
2	40	36.20	1.3
3	60	36.70	1.3
4	80	37.15	1.3
5	100	37.91	1.4
6	120	38.80	1.4
7	140	39.90	1.3
8	160	41.2	1.2
9	180	42.5	0.3

Table no: 8.2.1: Charging Performance at no load for every 20 min.

Above Table no: 8.2.1 shows Charging Performance at no load for every 20 min.

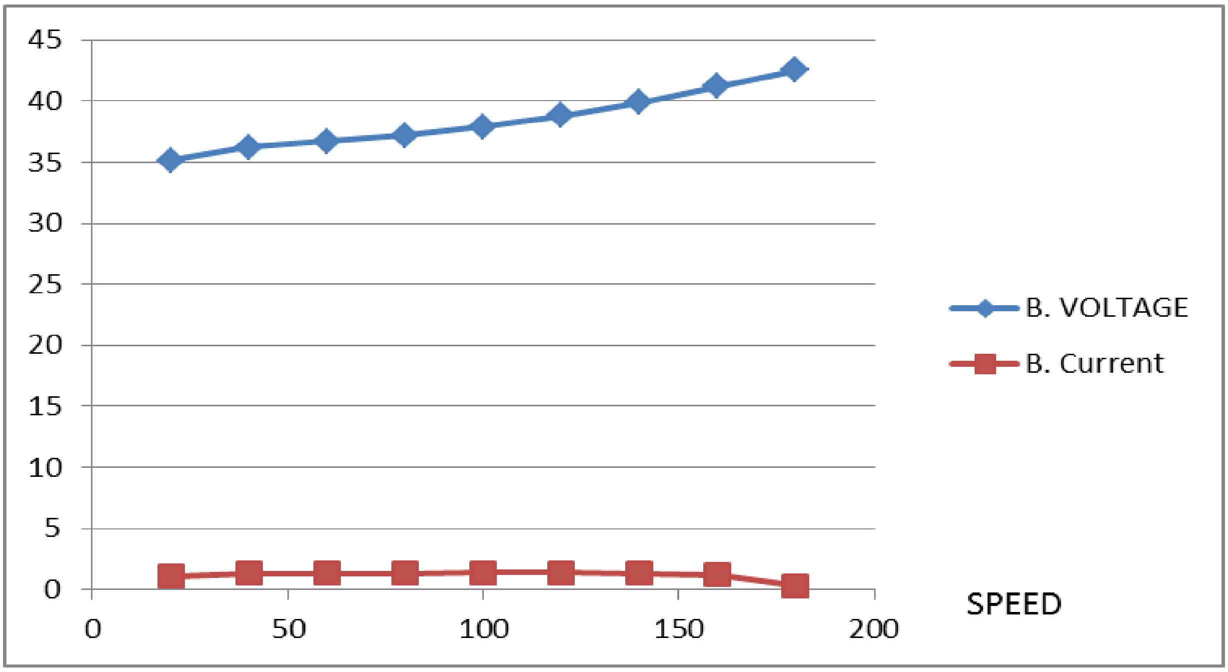

Fig 8.2.1: Graph for Battery Charging Performance at no load for every 20 min.
Above Fig 8.2.1 shows Graph for Battery Charging Performance at no load for every 20 min.

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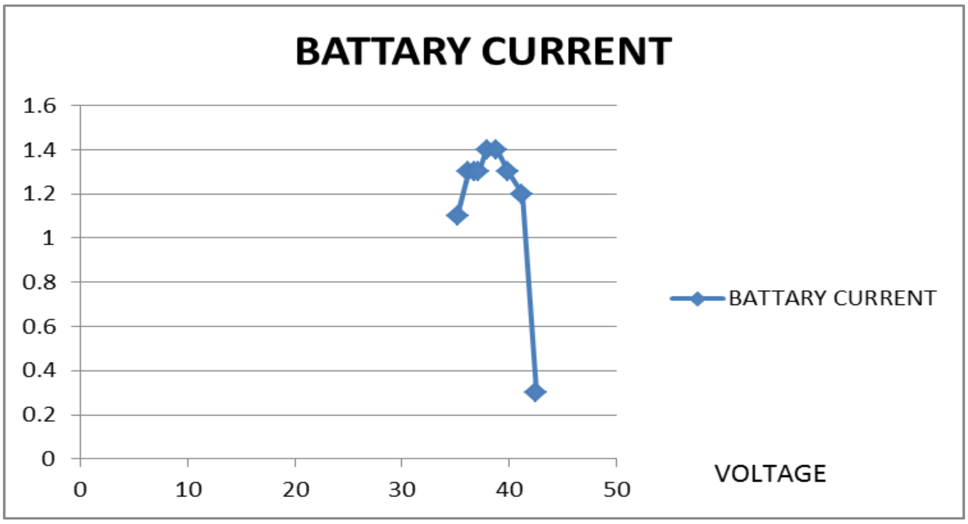

FIG: 8.2.2: I-V Graph for Battery Charging Performance at no load

Above FIG: 8.2.2 shows I-V Graph for Battery Charging Performance at no load

SR NO	TIME	BATTARY VOLTAGE	BATTARY CURRENT
1	00	34.80	0.9
2	10	35.19	1.0
3	20	35.69	1.0
4	30	36.21	1.1
5	40	36.55	1.1
6	50	36.74	1.1
7	60	37.12	1.2
8	70	37.27	1.1
9	80	37.71	1.1
10	90	37.90	1.0
11	100	38.70	1.0
12	110	39.30	0.9
13	120	39.90	0.9
14	130	40.60	0.9
15	140	41.50	0.9
16	150	42.20	0.6
17	160	42.30	0.3
18	170	42.30	0.1
19	180	43.00	0.0

Table no: 8.2.2: Charging Performance at no load for every 10 min.
Above Table no: 8.2.2 shows Charging Performance at no load for every 10 min.

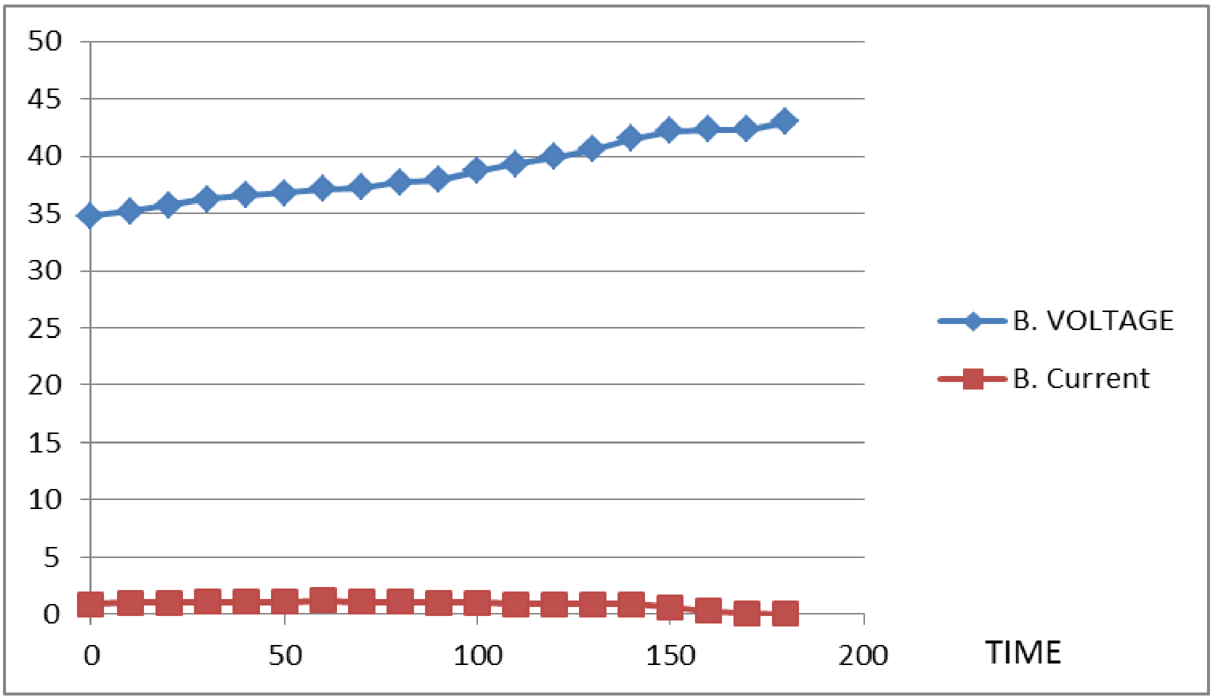

FIG:8.2.3 Graph for Battery Charging Performance at no load

Above FIG:8.2.3 shows Graph for Battery Charging Performance at no load.

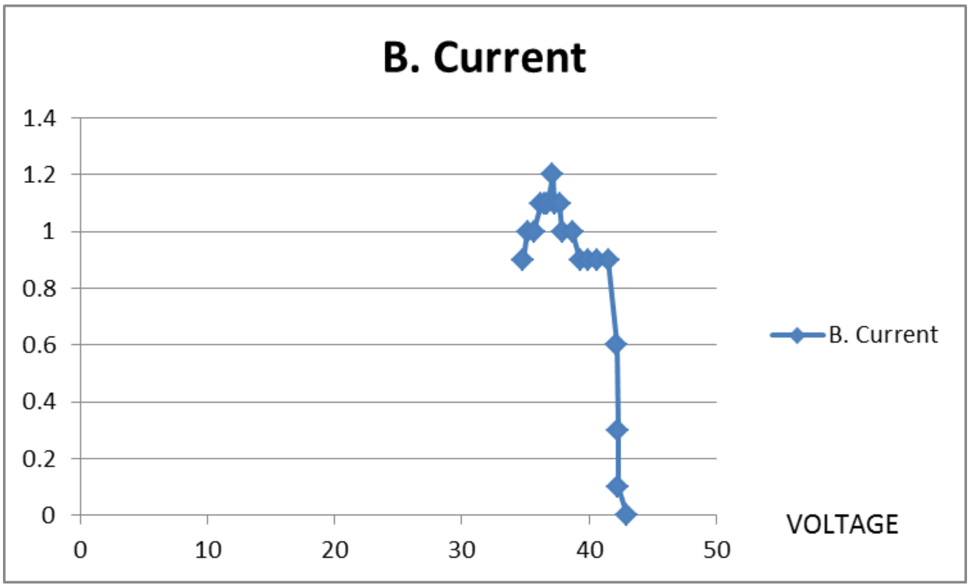

FIG 8.2.4: I-V Graph for Battery Charging Performance at no load

Above FIG 8.2.4 shows Graph for Battery Charging Performance at no load

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8.3 Battery Discharging Performance at load

SR. NO.	DISTANCE	BATTERY VOLTAGE
1	2	41.9
2	4	40.5
3	6	38.9
4	8	38.0
5	10	37.0
6	12	35.8
7	14	35.7
8	16	34.8
9	18	33.1
10	20	31.1

Table: 8.3.1 Battery Discharging Performance at load

Above Table: 8.3.1 shows Battery Discharging Performance at load

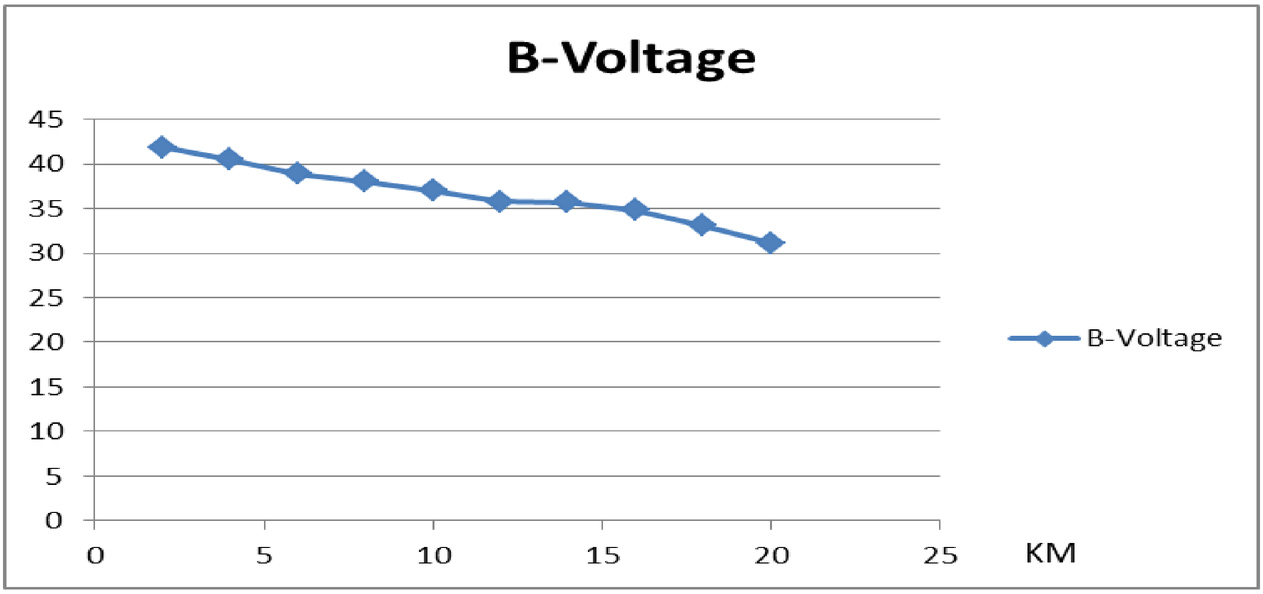

FIG:8.3.1 Graph for Battery Discharging Performance at load.

CONCLUSION

With the growing application of natural resources of petrol, diesel it is necessary to shift our way towards anouther resources like the Electric bike and others because it is necessary to identify new way of transport. Electric bike is a modification of the old cycle by using electric energy and solar energy if solar panels are provided, that would sum up to grow in energy production. Since it is energy efficient, electric bike is affordable to anyone. It can be used for shorter distances by people of any age. It can be used throughout the year. The most vital feature of the electric bike is that it does not consume fossil fuels thereby saving crores of foreign money. The second most important feature is it is pollution free, eco – friendly and noiseless in operation. It can be charged with the help of AC adapter if there is an emergency. The Operating cost per/km is very less. Since it has fewer components it can be easily dismantled to small components, thus requiring less maintenance. It can go near about 20-25 km in single charge.

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