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Fabrication and Experimental Analysis of Lithium-Ion Battery Based Smart Electric Bicycle

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Abstract: *Building a Project plays a vital role in improving skills as well as in boosting career opportunities for an engineer. Designing and building any machine comes with its share of success and failures. This is a way of brainstorming, creating new ideas which help in betterment of our future and also opens to other new ideas. The Electric vehicle has been popular for the last two decades and now its market is also booming in India. Bicycle being the greenest mode of transportation comes with a drawback that cannot be ignored in this fast-paced world. Transportation is now greeted as time saving process. So, this is where electric bicycle mainly came into picture. People need a green, health preserving, fast mode of transportation and E-bicycle gave it all. More than just being these things electric bicycles is also able to generate back electric power by the use of pedaling of wheels through regenerative mode of the motor used. Our Aim is to making a Cheapest Rate Electric Bicycle from Market Price, which will be run on li-ion battery as an energy storage device. The work includes simulation of electric vehicle using MATLAB/Simulink to evaluate the rate of working parameters i.e., state of charge, voltage and current w.r.to time and to evaluate the distance covered related to the velocity and acceleration of the vehicle. Further the same results are validated with experimental results after fabrication of the proposed e-bicycle. This project will be a novel solution for the persons whose daily distance of travelling is not more than 10 km of range and efficient reuse of scrap old cycles, also this project includes concept of generating electrical energy through mechanically paddling, thus this project is good solution for exercise and generated energy can be further used for small scale applications like mobile charging of glowing the bulb in night mode.*

Keywords: E-mobility, E-bicycle, Lithium-ion Battery, Battery Pack, Regeneration of Energy, etc.

I. INTRODUCTION

We all are living in the future. With time, technology has improved our lives. Nowadays, most of the countries are using electrical bicycles. The use of cycle than vehicles is always green to the environment, but an E-bike is the biggest adoption of green transportation of the decade. Just think of E-bike in place petrol operated scooters rather than a normal bike. An E bike uses rechargeable batteries which can travel up to 25 to 45 kmph. As a result, it is faster than the normal cycle to reach your destination quicker and in better shape. E-bike is an electric and power-assisted bike which is one of the fastest-growing technologies of the bicycle industry.

This bicycle uses an electric motor to help you along. So, you can ride it like a normal bicycle, but with less effort. A pedal-operated E-bike is the most popular option. As you pedal the bike, the motor gets powered, and it works. In comparison, a throttle-assist E-bike is similar to a normal motorbike. It operates as you accelerate the throttle. Electric bicycles are available in many styles, from commuter bikes to full-suspension mountain bikes. The power output of these pedal-operated motors is typically governed by regulations.

Mostly, they are available with an output power of around 250 watts. Bikes fitted with a throttle-based motor system have slightly different output regulations. It can be available with a maximum power of around 200 watts, while speed remains limited to 25 kmph.

Problem Statement:

Nowadays, increasing in air pollution due to extensive use of petroleum fuels in IC engine-based vehicles in urban areas and Rising Fuels Prices Every day, Scarcity of fuels. If we want to control all This, Then the Best probable solution is Electric Vehicle. In this work we have taken example as e-bicycle. As we can see the average transportation for a common man is 10 to 20 km on daily basis so using smart e-bicycle having all features similar to conventional two wheelers we can control use of petroleum fuel which indirectly help to reduce environmental pollution. Also, we are focusing on charging of the bicycle battery by pedaling mechanism so that a person will pedal the bicycle during time of exercise which creates mechanical energy; the same can be converted to electrical energy for charging the batteries.

Objectives:

1. To study and analyze various researches work done earlier related to e-mobility for different applications and road conditions. After that to finalize the further scope of work in the same field through literature survey.
2. To make CAD model of proposed setup considering e-vehicle application for light weight vehicle i.e., e-bicycle.
3. To do technical and theoretical analysis of various batteries used in electric vehicle with its manufacturing for battery pack and various circuit connections.
4. To finalize best suitable type of battery for proposed e-bicycle.
5. Simulated analysis of circuit connection for proposed e-bicycle with initial working parameters to know the behavior of various performance parameters i.e., variation of state of charge, current and voltage w. r. t. time.
6. Manufacturing of battery pack as per the energy and power calculations for proposed setup to do the experimental analysis.
7. Validation of the project by comparative analysis of experimental and simulated results for proposed applications.

Methodology

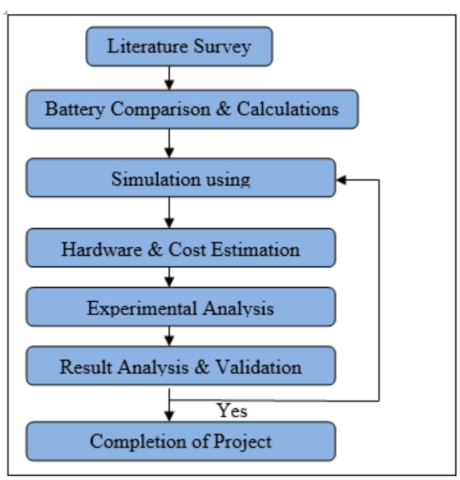

Figure 1: Methodology of the Project

Scope & Proposed Idea of the Project:

The basic theme of our project is to Fabricate and cost-efficient e-bicycle which should satisfy all performance parameters and can be used for exercise as well as transportation for limited distance. Therefore, this proposed setup a light electric vehicle application with a maximum weight carrying capacity 100kg. We are going to do the comparative analysis of various batteries to finalize best suited energy source for electric vehicle application.

Figure 2: Proposed Experimental Setup

II. LITERATURE SURVEY

Table 1: Summary of Literatures

Name of Author	Title of Paper and Year of Publications	Remarks
Sachin S. Kakkattil, K.S. Sandeep	Design And Fabrication of Foldable Electric Bicycle (2020)	This Paper Illustrates the idea of transforming an ordinary bicycle into a foldable electric bicycle and the fundamentals of its construction. Important Task is Design and Development of Folding Mechanism. This Paper Main Aim is to Combine the Benefits of an EB & Foldable Bicycle.
Nguyen Ba Hung, Ocktaeck Lim.	A Review of History, Development, Design and Research of Electric Bicycles (2019)	This Paper Review and Summarized EB related Literature to show the history, Development and potential markets of Ebs worldwide. The Specification of Ebs is Classified according to designs and them components. The Rules and Regulations of using EBs in several World Regions are discussed.
Hanghang Zhu, Zhi Pei	Data-Driven Layout Design of Regional Battery Swapping Stations for Electric Bicycles (2020)	This paper studies the layout of battery swapping stations for electric bicycles in a community. The problem is first formulated as a nonlinear mathematic programming model. A simulated annealing-based algorithm is applied to solve this problem.
Jaewin Sung, Nguyen Ba Hung	A Study of the dynamic characteristics and required power of an electric bicycle equipped with a semi-automatic Transmission (2017)	The Objective of this study is to investigate dynamics characteristics and to optimize required power of an EB equipped with a Semi-automatic transmission. In this simulation, they analyze dynamic & operation characteristics of an EB at each gear ratio. Through this simulation an optimized analysis is conducted to maximize the power generation of EB.

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Peter K. Joseph, D. Elangova	Linear Control of Wireless Charging for Electric Bicycles (2019)	This Paper Presents a Customized Linearization Technique for the wireless power chargers for EBs application. Wireless power transformer will act as a conventional wired transformer and no additional sensors are required to realize its performance. Simple Close loop control is implemented based on this linearized region.
Huai Chuangfeng, Liu Pingan	Measurement and analysis for lithium battery of high-rate discharge performance (2011)	In this paper, measure and analysis their high-rate discharge performance for two kinds mainstream lithium battery of lithium polymer and LiFePO4 Battery. The results show that lithium polymer battery is more effective than LiFePO4 Battery in constant-current discharge performance, power density and energy density. But in safety charge-discharge and durability, LiFePO4 Battery has some advantages
Salvatore Mellino, Antonella Petrillo	A Life Cycle Assessment of lithium battery and hydrogen-FC powered electric bicycles: Searching for cleaner solutions to urban mobility (2016)	In this study, Life Cycle Assessment is applied to evaluate the environmental burdens of the production of these two vehicles and compare their environmental performances per 100 km travelled. The study, not only includes vehicle road operation but also embraces production and distribution of bikes, electric battery, PEMFC and energy carriers (electricity and hydrogen) over the vehicle's entire lifetime.
Lorenzo Stilo, Diana Segura-Velandia	Electric bicycles, next generation low carbon transport systems: A survey (2020)	This investigation discusses results from a survey on end-user preferences for future e-Bikes that will be developed in coming years. Data were analyzed to rank the importance of desired functionality to improve the uptake of cycling within urban environments. This survey showed how respondents expressed a desire for a more intelligent, secure and adaptive e-Bikes.
Wenqiu Liu, He Liu	Life cycle assessment of power batteries used in electric bicycles in China (2020)	This study quantified the full life cycle environmental performance of LABs (lead-antimony-cadmium, Pb–Sb–Cd, and lead-tin-calcium, Pb–Sn–Ca) and LIBs (lithium-nickel-cobalt-manganese, NCM, and lithium-iron-phosphate, LFP) through the life cycle assessment methodology. The results showed that the material extraction and processing and the battery use stages were the main processes that affected the overall environmental performance.
Sheng Jin a, Xiaobo Qu	Estimating cycle way capacity and bicycle equivalent unit for electric bicycles (2015)	Capacity and bicycle equivalent units (BEUs) for E-bikes were two most important parameters for the planning, design, operation, and management of bicycle facilities. The results indicated that, with around 70% share of E-bikes, the mean estimated capacity was 2348 bicycle/h/m. The effects on the capacity of the proportions of E-bikes, gender of cyclists, age of cyclists, and cyclists carrying things were also analyzed.
Daniel Meyer, Wenlong Zhang	Heart rate regulation with different heart rate reference profiles for electric bicycle riders (2015)	In this paper, they propose a new nonlinear control strategy for electric bicycles that adjusts the motor assistance automatically to maintain a desired heart rate level of the cyclist. The control algorithm uses the current heart rate, torque and cadence of the rider as inputs, and adjusts the assistance of the motor adaptively. They present simulation as well as experimental results for different reference heart rate profiles to verify the performance of the controller.
Sigal Kaplan, Dagmara K. Wrzesinska	The role of human needs in the intention to use conventional and electric bicycle sharing in a driving-oriented country (2018)	They adopt the new mobilities perspective to look at cycling and e-cycling. Human needs are related to the intention to use conventional and electric bicycles. Functional and relational needs relate to the use of bicycle sharing. Self - actualization needs associate with the use of conventional bicycles only.

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III. THEORETICAL AND TECHNICAL ANALYSIS

Table 2: comparative analysis of battery used in electric vehicle

Kinds of Batteries	Features	Advantages	Disadvantages
Lead Acid	It was the 1st Battery that could be recharges by passing a reverse current through it.	Lead-acid batteries are cheap and could be recycling easily. They can be easily delivered to customers due to many suppliers worldwide.	Lead-acid battery is much heavier than other batteries, thus lifting it can cause injury for user. Dependence on hazardous and restricted lead.
Nickel-Cadmium	The positive (Ni) and negative (Cd) electrode plates, isolated by the separator, are rolled in a spiral shape inside a metal case (jelly-roll design) to allow delivering a much higher maximum current than equivalent size alkaline cell.	It has more capacity than lead-acid battery. Besides, it has a faster charge rate and fewer maintenance requirements. It can be created with a wide range of sizes depending on performance.	One of the big disadvantages of this battery type is memory effect in which NiCd battery gradually loses their maximum energy if they are repeatedly recharged after being only partially discharge.
Nickel-Metal Hydride	The chemical reaction at the positive electrode is similar to that of the NiCd battery; however, its negative electrode uses a hydrogen-absorbing alloy instead of cadmium. Hydrogen ions are stored in a metal-hydride structure that is the negative electrode of the nickel-metal hydride battery. Polyolefin nonwovens are used as a typical material for the separator.	Similar to NiCd battery, it is simple in transportation and storage. However, it is more Environmentally friendly and less susceptible to memory effect than a NiCd battery. In addition, it also offers more energy per unit volume or weight than corresponding NiCd battery types.	It is more expensive than NiCd battery. Its service life could be reduced if a deep discharge occurs. Aside from the limited-service life, it has a high self-discharge which is also affected by ambient temperature. In addition, it requires complex charge algorithm.
Lithium-ion	In which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging in general, the negative and positive electrodes of a lithium-ion cell are made from carbon & metal oxide. The electrolyte is a lithium salt	Li-ion battery is lighter than other rechargeable batteries in view of battery capacity. It has a high energy density along with a very small Memory effect. Its rate of self-discharge is much lower than that of NiCd and NiMh batteries. It is ideal for use in EBs due to its high energy efficiency.	The cost is one of disadvantages of Li-ion battery. It could be damaged due to over-heating, overcharging, and over-discharging. it is required protection to ensure its safe operating limits.
Lithium-ion Polymer	The Li-ion batteries using liquid electrolyte between negative and positive electrodes, LiPo batteries use polymers with high conductivity semisolid (gel) to form an electrolyte. In addition, the LiPo battery can use a solid polymer electrolyte such as poly (acrylonitrile) (PAN), poly (vinylidene fluoride) (PVdF) and poly (ethylene oxide).	It has a high energy density with lightweight, and can be created in a wide range of sizes. The charging capacity of LiPo battery is not much lost as compared to Li-ion battery, thus its life span is higher than Li-ion battery. Besides high energy density and lightweight, it is good in safety performance, and can be used as a power source for electric bicycles.	The price of LiPo batteries is higher than that of Li-ion batteries. Energy density and cycle number of LiPo battery are smaller than Li-ion battery. In addition, it has no standard shape, and requires special care during storage, charging and discharging.

Working principal of lithium-ion battery:

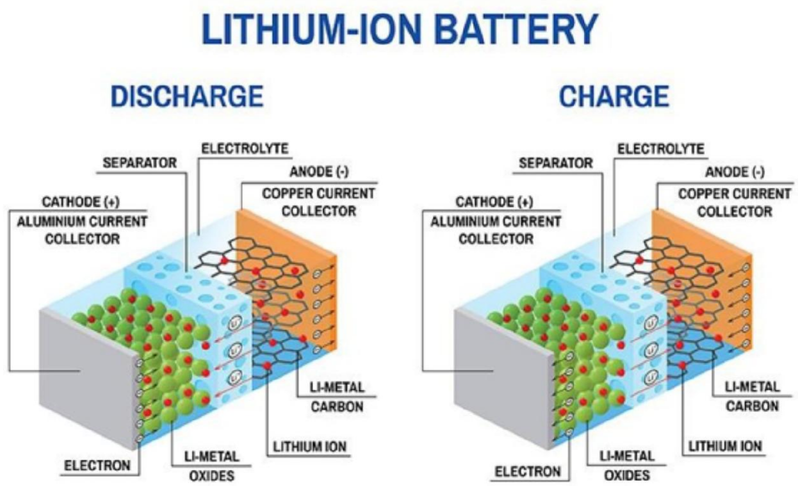

Figure 3: Lithium-ion Battery Working

Lithium-ion Battery is rechargeable type of battery. Lithium-ion Battery is made up of anode, cathode, separator, electrolyte, and two current collectors (positive and negative). The negative and positive electrodes of a lithium-ion cell are made from carbon and metal oxide, respectively. The anode and cathode store the lithium. Separator is used to prevent physical contact between the anode and cathode. Lithium ions move from the negative electrode to the positive electrode during discharge and back when charged.
Li-ion battery is lighter than other rechargeable batteries in view of battery capacity. It has longest life. It has highly efficient Charging. It has a high energy density along with a very small memory effect. It does not require maintenance. Its rate of self-discharge is much lower than that of NiCd and NiMh batteries. It is ideal for use in EBs due to its high energy efficiency. That's why we take Lithium-ion battery over the other batteries.

Table 3: comparative analysis of motors used in electric vehicle

Basic Parameters	AC Motor	DC Motor
Nature Of Input Current	Alternating Current is the main input power.	Direct Current is the main input power.
Supply Sources	Three Phase or Single Phase	Energy is obtained from battery cells etc.
Number of Terminals	There are three input terminals RYB	There are two input terminals Positive and Negative.
Carbon Brushes	There are no Carbon brushes.	There are Carbon brushes in DC Motor.
Applications	Suitable for large & industrial applications.	Suitable for small and domestic applications.
Starting	AC motor are not self-starting. It requires some external starting equipment's.	DC motor are self-starting equipment's.
Position of Armature	The Armature is Stationary and magnetic field rotates.	The Armature rotates while the magnetic field is stationary.
Maintenance	Less Expensive as compared to dc motor.	DC motor is more expensive.

CAD Modeling:

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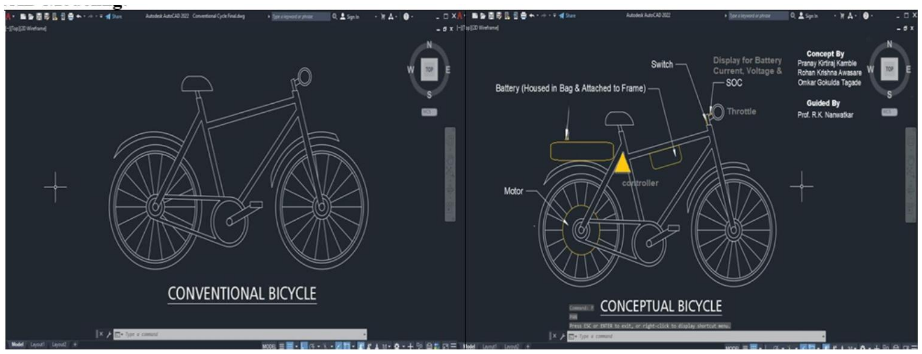
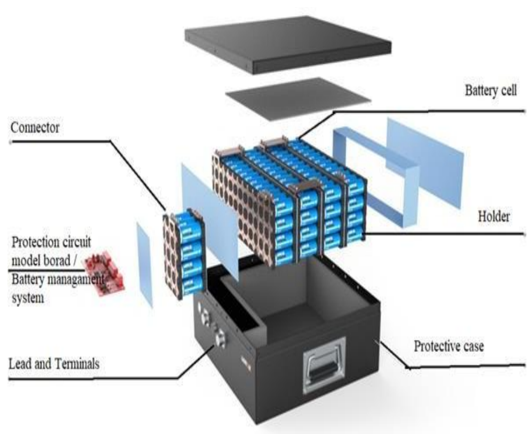


Figure 4: Conventional vs proposed e-bicycle

Battery Pack Assembly:

Lithium battery pack technique refers to the processing, assembly and packaging of lithium battery pack. The process of assembling lithium cells together is called PACK, which can be a single battery or a lithium battery pack connected in series or parallel. The lithium battery pack usually consists of a plastic case, PCM, cell, output electrode, bonding sheet, and other insulating tape, double-coating tape, etc.

1. Lithium cell: The core of a finished battery.
2. PCM (Protection Circuit Model) and BMS (Battery Management System): Protection functions of over charge, over discharge, over current, short circuit, NTC intelligent temperature control.
3. Plastic case: the supporting skeleton of the entire battery; Position and fix the PCM; carry all other non-case parts and limit.
4. Terminal led: It can provide a variety of terminal wire charging and discharging interface for a variety of electronic products, energy storage products and backup power.
5. Nickel sheet/bracket: Connection and fixing component of the cell.



XTT li-ion battery of 18 x 65 mm dimensions

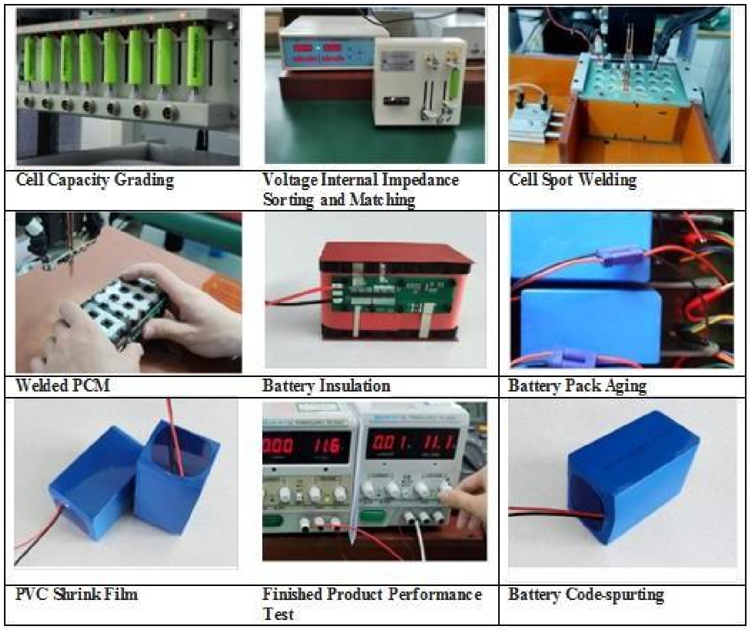


Figure5: Structural configuration and assembly of Lithium-ion battery pack

Precautions for Lithium Batteries in Series and Parallel

1. Don't use batteries with different brands together.
2. Do not use batteries with different voltages together.
3. Do not use different capacities or old and new lithium batteries together.
4. Batteries with different chemical materials cannot be used together, such as nickel metal hydride and lithium batteries.
5. Replace all batteries when electricity is scarce.
6. Use the lithium battery PCM with corresponding parameters.
7. Choose batteries with consistent performance. Generally, distributing of lithium battery cells is required for series and parallel connection. Matching standards: voltage difference≤10mV, impedance difference ≤5mΩ, capacity difference ≤20mA.

Battery Management System (BMS) Cell Protection

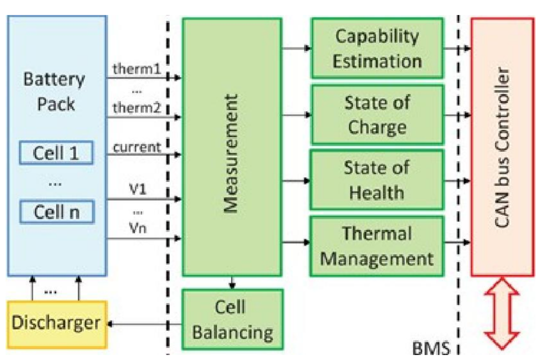


Figure 6: Battery Management System

A BMS continuously monitors each cell's voltage. If the voltage of a cell exceeds the others, the BMS circuits will work to reduce that cell's charge level. This ensures that the charge level of all the cells remains equal, even with the high discharge (> 100Amps) and charge current (>10Amps). A cell can be permanently damaged if over-charged (over-voltage) or over-discharged (drained) just one time. The BMS has circuitry to block charging if the voltage exceeds 15.5 volts (or if any cell's voltage exceeds 3.9V). The BMS also disconnects the battery from the load if it is drained to less than 5% remaining charge (an over-discharge condition). An over-discharged battery typically has a voltage less than 11.5V (< 2.8V per cell).

IV. SIMULATION AND EXPERIMENTAL ANALYSIS

Simulation (software used MATLAB / Simulink 2020)

Table 4: Parameters for simulation

Vehicle Body Parameters	DC Motor Parameters	Battery Parameters
Mass - 100kg Number of wheels per axle- 2 Horizontal distance from CG to front axle – 1.4m Horizontal distance from CG to rear axle- 1.6m CG height above ground- 0.5m Gravitational acceleration- 9.81 m/s^2	Field type – Permanent Magnet Armature inductance- 12e-6H No-load speed- 10000 rpm Rated speed (at rated load) – 8000 rpm Rated load (mechanical power) – 250W Rated DC supply voltage – 25.1V	Nominal voltage (V) –25.1 Rated capacity (Ah) –10 Initial state-of-charge (%) – 100 Battery response time (s) – 15

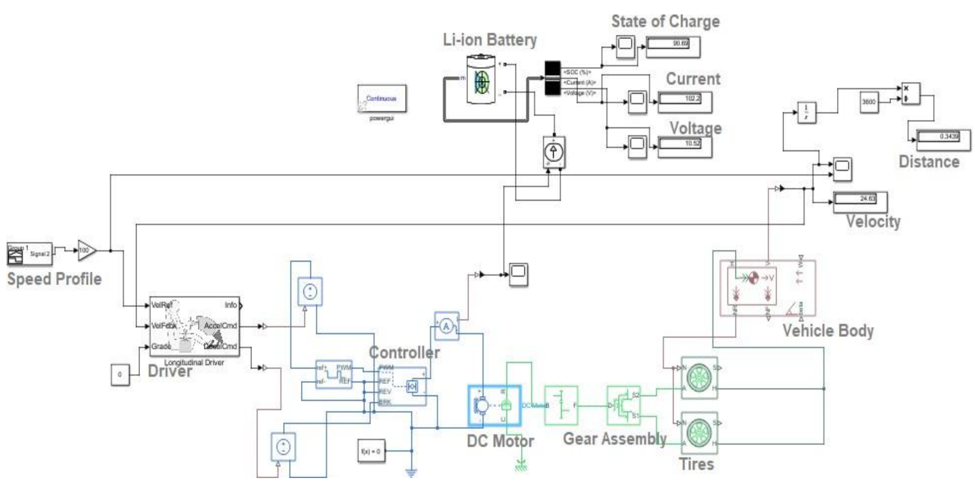
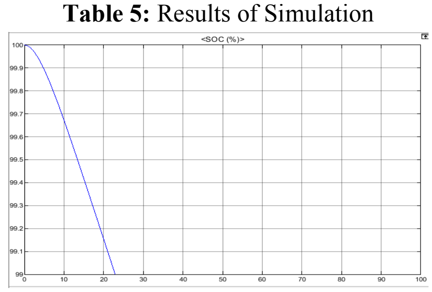


Figure 7: Simulation model of Electric Vehicle

Table 5: Results of Simulation



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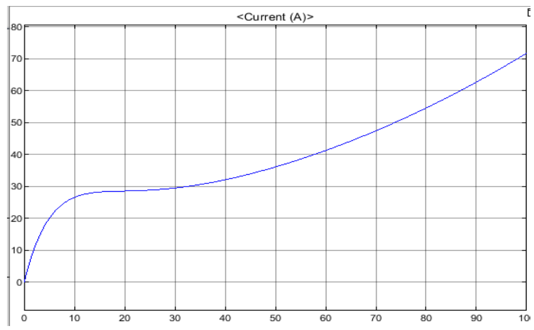
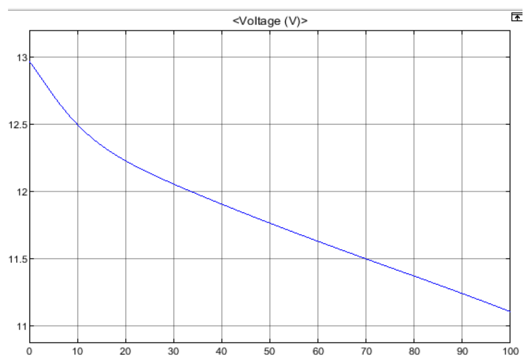
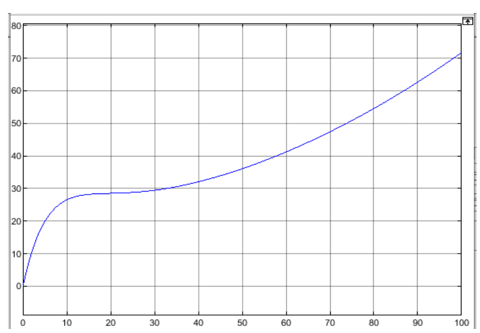


Current (A)



Voltage (V)



Speed (N)

Experiential Analysis

V. CONCLUSIONS

1. We studied various research work done earlier related to e-mobility, It is found that very less work has been done on electric vehicle as per Indian road conditions. Also, further research work can be done on energy conversion of mechanical energy into electrical energy by pedaling the bicycle to charge the battery
2. CAD model of the proposed setup found to be optimizing solution for replacement of conventional two wheelers to satisfied daily basic needs of human beings and for exercise purpose.
3. The theoretical analysis of various batteries and its connections we conclude that both series and parallel connection are needed for efficient battery pack. We got approximately 24v and 10Ah through battery calculation. Connection of batteries, 7 in parallel and 4 connections in series Connections by following all safety aspects and IS Standards.

4. The simulation work done using MATLAB Simulink shows variations of various battery and performance parameters of vehicle w.r.t. Time. Noticeable results are State of charge and Voltage were continuously decrease linearly, Velocity of e-vehicle And Current variation was non-linear w.r.t time as shown simulated results.

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