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by

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CERTIFICATE

Certified that the **Project Work** entitled ***"DESIGN OF ELECTRIC POWERED BICYCLE"*** is a bonafied work carried out by **Dhanyashree G-1GV16EE003, Vijayasree M- 1GV16EE021, Yogesh Kumar H S-1GV16EE022** and **DINESH V- 1GV17EE400** in the partial fulfillment for the award of degree of Bachelor of Engineering in **Electrical and Electronics Engineering** of the **Visvesvaraya Technological University,** Belagavi during the year 2019-2020. It is certified that all corrections/suggestions indicated for the assessment have been incorporated in the report deposited in the departmental library. The Project report has been approved as it satisfies the academic requirement in respect of **Project Work- 15EEP85** prescribed for the Bachelor of Engineering Degree.

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ABSTRACT

The e-bike is a human electric hybrid vehicle. Basically, these bikes are for people who want an alternative to a car, get exercise, go fast without increased effort, and get you where you want to be. The e-bike is made not to leave the rider completely idle but to assist in the movement over hills as well as flat ground. Peddling on the part of the rider can be used both to move the bicycle and to recharge the batteries. It's an amazing, fast and efficient vehicle that respects the environment. With this vehicle, it is possible to enjoy a leisurely and relaxing cruise and arrive at destinations (such as work) at the same time. A new model of power-assisted bicycle has been designed, set up and tested. Electric bicycles have been gaining increasing attention worldwide. The electrically assisted bikes are normally powered by rechargeable battery, and their driving performance is influenced by battery capacity, motor power, road types, operation weight, control, and, particularly, by the management of the assisted power. A classification of the electrically assisted bikes can be based on two categories a first kind is represented by a pure electric bike, which integrates electric motor into bicycle frame or wheels, and it is driven by motor force just using a handlebar throttle; a second kind is a power-assisted bicycle, or called pedelec hereafter, which is a human–electric hybrid bicycle that supports the rider with electric power only when the rider is pedalling. The pedelec are characterized by a driving torque due to both an electric motor torque and a rider one [2]. Consequently, the management of the assistance torque is of particular interest in order to reach the desired performances in terms of driveability and comfort.

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Chapter 1

INTRODUCTION

Global warming and scarcity of traditional resources are becoming major problems in the current scenario. Due to the economic challenges India is facing in automotive sector the hybrid bicycle market has a huge growth potential. People try to move towards "clean" energies. These facts among others will leverage the electric bicycle industry on the top of the agendas not only in India. Moreover, the vision of an electric engine, which supports the muscular strength, became reality. Bicycles with such a supporting electric engine belong to the innovative vehicles, which are wholeheartedly suitable for everyday life. In face of continuous climate discussions and permanent traffic jams, electric bikes have the potential of solving such issues and making a more energy efficient and environment friendly mobility possible. Accordingly, a continuous trend towards electric bicycles can be expected simultaneously in whole of India. So, it becomes very necessary to manufacture the electric cycles so cheaply that the common people in our country can afford to buy it. The currently existing electric scooters are far more costly and due to budgetary constraints, a middle-class person cannot afford such a locomotive at his place. Along with the development of technologies the theory must be also implemented to design and Manufacture a product that can be sold off at a greater frequency, which has a very low production cost and one that is of good quality [1]. In order to implement all the above ideas, we planned to make the design and product in such a manner that it can be competed with the existing "e-Bikes" in the market.

The large use of the travelling vehicles has increased the problems connected to the air quality and to the use of petroleum. The human sensibility for the energetic and environmental problems is encouraging the research in alternative solutions for the automotive field, as multiple-fuelling, hybridization and electrification. At the same time, particularly as concerns urban areas, new standards have imposed substantial modifications in the mobility. In this context, a vehicle as the electrically assisted bike can be considered a promising alternative vehicle for both personal mobility and goods delivery, especially for small and medium distances: an assisted bike is able to move with an average speed equal to the typical one of the town traffic but it requires energy for its mobility that is very close to the necessary energy for the displacement of the transported people. The electrically assisted bikes are normally powered by rechargeable battery, and their driving performance is influenced by battery capacity, motor power, road types, operation weight, control, and, particularly, by the management of the assisted power [2]. A classification of the electrically assisted bikes can be based on two categories:

a) first kind is represented by a pure electric bike, which integrates electric motor into bicycle frame or wheels, and it is driven by motor force just using a handlebar throttle
b) second kind is a power-assisted bicycle, or called pedelec hereafter, which is a human–electric hybrid bicycle that supports the rider with electric power only when the rider is pedalling. The pedelecs are characterized by a driving torque due to both an electric motor torque and a rider one.

Consequently, the management of the assistance torque is of particular interest in order to reach the desired performances in terms of drive ability and comfort.

1.1 History of the Project

- First models of electric bicycles appeared in late 19th century. US Patent office registered several electric bicycles patents since 1895 to 1899 (Ogden Bolton patented battery-powered bicycle in 1895, Hosea W. Libbey patented bicycle with double electric motor in 1897 and John Schnepf patented electric motor with roller wheel).
- Electric bicycle is the only transportation device that managed in the last 20 years to take significant part of the bicycle market share. With its simple design that closely mimics traditional bicycle, small and efficient electric motor and easy control methods, it successfully experienced rapid sales growth since 1998.
- Today, it is estimated that there are approximately over 120 million electric bicycles in use in China alone. Use of electric bicycles in Europe and North America is growing fast, with the reported yearly sales of one and a half million units.
- One of the most appealing features of electric bicycles is that it has no harmful emissions from combustion engine with zero chances of Earth pollution [3]. Even if we include the cost of frequent battery changes, e-bike is many times more environment friendly than any other public road transportation device.

1.2 Reason for Selecting the Project

Today's world there is a lot of need for change to improve the present ecological condition. The bicycles invention has had an enormous effect on society, both in Terms of culture and of advancing modern methods. In the world we live in today, you cannot go very far without considering or being told to be more "green" and do things that are better for their environment. With the E-Cycle, you never have to worry about that again. With rechargeable batteries, on top of the manually powered design of a bike, the E-Cycles will get you most places a car will all while reduced your carbon footprint.

An E-Cycle also is going to be save you a fortune in the need-to-repair department. While E-Cycles or its components might seem expensive, an unforeseen car repair pales in comparison to an E-Cycles purchase. E-Cycle don't have oil changes and lack many other maintenance requirements. E-Cycle is the biggest adoption of green transportation of the decade. 'Cycling is already green' you may say, but it's more than that [4]. Think about them in small petrol scooters rather than normal bicycles. E-Cycle use rechargeable batteries that can travel up to 25 to 45km/h than compare to any other vehicles.

1.3 Equipments Used in This Project

- Bicycle
- Batteries
- Charger
- Fly Wheel
- Chain Drives
- PMDC Motor
- Controller

Chapter 2

LITERATURE SURVEY

A literature survey or a literature review in a project is a type of review articles. It is a scholarly paper, which includes the current knowledge including substantive findings, as well as theoretical and methodological contributions to a particular topic. Literatures reviews are secondary sources, and do not report new or original experimental work. It is a basis for research in nearly every academic field. Concentrate on the own field of expertise.

2.1 Details of Literature Survey

1) This section of the paper deals with the mechanical design of the system and the various parts used in the system integration. The power transmission system consists of the motor, the chain sprockets, flywheel, housing and the rear wheel. However, before we could select these components, we performed some basic calculations relating energy transfer through the system. Primarily we focused on the current requirements of the system, and a number of torque-speed relationships. Both the acceleration on flat ground and hill climbing ability of the system depend on how much torque can be delivered by the various system components. Before we could size the batteries, we needed to estimate when the motor would demand the most current and the duration that it would draw its peak current. These situations would be at start up (acceleration) and when climbing a gradient. The main components affected by the following calculations are the motor and the battery. The PMDC motor had to be regulated by a mechanism which involved a DC motor driver. This driver had specifications able to withstand up to 20A which was key to this project as varying loads would undoubtedly draw more current. So, the rated current rating had to be high enough to withstand this. The driver is controlled by an Arduino Board which receives input signals via. a potentiometer (variable resistance) [1]. The Arduino board was programmed in such a way that varying the resistance in the potentiometer would result in an equivalent value of bytes which the program could comprehend and translate to proportional DC motor speeds.

2) A new model of power-assisted bicycle has been designed, set up and tested. The main innovative solutions for the pedalled prototype are described in the present paper: the electric motor position; the new mechanical transmission; the low cost measurement system of the driving

torque; the special test rig. Differently from a common approach, in which the electric motor is located on one of the three hubs of the bicycle, the idea of the pedalled prototype consists of an electrical motor in the central position that, by means of a bevel gear, transmits the torque on the central hub. The other innovative solution is represented by the motion transmission from the motor to the pedal shaft, achieved by two different gearboxes: the first one is a planetary gearbox and the second one is a simple bevel gear. The pedalled prototype contains also a new low cost measurement system of the driving torque based on a strain gauge load cell located on one side of the rear wheel, between the hub and the frame. Moreover, a commercial cycling simulator has been suitably modified in order to properly install the different sensors for the measurement of the performance of the pedalled. The test rig is able to reproduce an aforethought route or paths acquired during road tests, to measure the performance of the e-bike in terms of instantaneous power and speed. The experimental test rig can simulate the resistant torque of a predetermined track and it aims to test and to optimize the control strategy available on the electronic control unit [2]. The authors have also conducted an environmental analysis of the developed pedalled, in particular comparing the e-bike with a thermal moped, in terms of environmental impact

3) This paper reviews possible approaches to the design of an electric bicycle with an emphasis on three different domains – electrical, mechanical and system level design. It reviews the available solutions to a wide range of issues in each of the above mentioned domains. After grouping the solutions presented and classifying them on a domain basis the paper presents a classification on the ways to design an electric bike, so that a designer can easily obtain the required information in order to start their project. The primary aim of this paper was to present the various approaches that have been accumulated in the scientific literature to design an electric bicycle. In order to group them in some manner a new classification is proposed that groups the various issues that the designer is faced in three broad categories – system level domain design, electrical engineering domain design and mechanical engineering domain design. For each of the three domains the main issues are presented alongside the most popular ways to solve them [5]. The advantages and disadvantages in choosing a particular solution are also discussed.

4) Power assistant modes of e-bikes rely on manual switching, and its shock resistance is much worse than that of general vehicles and motorcycles. This work proposes a vibration reduction system for e-bikes. While cycling, the system switches the power assistant mode automatically and notifies riders according to collected sensing data for road awareness. In the system, we use the accelerometer for data collection and feature extraction on bumpy roads. Then,

we combine the geographical information for classification and use the classified results for e-bikes power assistant modes mapping. Finally, we implement a system prototype and evaluate the performance of the prototype. In this paper, we have proposed a smartphone-based accelerometer Road-aware Adaptive Vibration Reduction System for e-bikes. Our system is implemented into a prototype system on an e-bike. It collects and detects the impacts on bumps or even subtle vibrations during cycling sufficiently. The RAAS module switches the power assistant mode adaptively according to the collected data. By evaluating the performance of our prototype in the real-world experiment, we have shown that our system can effectively reduce the rider manual switching power assistant modes and inhibit the vibration in cycling [6]. As the future work, after collecting a large enough amount of data, we should consider to use some machine learning algorithms to improve the mechanism on mode switching.

5) This paper deals with the assessment of the dynamics of the road vehicles with emphasis on the

simplicity of the developed model on one hand and taking into account the dominant variables affecting the propulsion power on the other hand. The study is initiated by a state of the art regarding the modelling of the road vehicles dynamics. Then, a modified bicycle model is developed considering three inputs which are: (i) the wheel speed, (ii)the road slope angle, and (iii) the vehicle loading level, and one output that is the vehicle resistant torque. The paper is achieved by a numerical example aimed at the simulation of the dynamics of a road vehicle under different driving cycles. The paper was devoted to the assessment of the dynamics of the road vehicles. The study was initiated by a state of the art regarding the modelling of the road vehicles dynamics. Then, a modified bicycle model was developed considering three inputs the wheel speed, the road slope angle and the vehicle loading level, and one output that is the vehicle resistant torque. The derived model has been implemented in the Mat lab/Simulink environment which enabled the investigation of the vehicle dynamics under two driving conditions, such that the operation at constant wheel speed and variable road slope, and also the operation at constant road slope and variable wheel speed [7].A good correlation has been found between the variations of the wheel speed, the road slope, the loading level, and the vehicle load torque

6) Electric Power Assisted Bicycle (EPAC) is becoming a better means of transport that people like and pursue because of its environmental, healthy, convenient and economical characteristics. Compared to the conventional bicycle, EPAC reduces the pedal force and relieves the fatigue of the rider. Nowadays, there are few researches on the torque control approach

adaptive to road grade and load for EPAC. Therefore, this paper proposes a new torque control approach based on Model-Following Control (MFC), which can eliminate the impact of the road grade and the load by processing the signal of speed and trample force on the bicycle. Accordingly, the torque of motor can be adjusted to achieve the optimal effect of assisted-power in real-time. In result, the rider will obtain a better riding experience [8]. The simulation and analysis demonstrate the effectiveness and performance of the proposed torque control approach.

7) 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 paper presents a way of designing and implementing an electronic module for an e-Bike. The paper 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. The entire system has been implemented and tested. The results obtained are comparable with commercial e-Bikes, and the proposed implementation presents higher power autonomy Ratio. The results have been obtained using a 350W, 3-phase BLDC motor and a 36V / 5.5Ah Li-Ion battery pack, mounted on a 13kg bicycle. The use of Li-Ion cells has been taken into consideration after studying the e-Bike market and observing that many commercial e-Bikes use Lead-acid batteries [9]. The designed e-Bike is compared with a commercial e-Bike of about same cost and complexity.

8) Now day's non-conventional energy plays a dominant role in industries or environmental protection purpose. Instead of using fuel operated vehicle we can use such sources to charge the battery which do not harm the environment. We know in India millions of bike travels on rod and cars which emits a large amount of carbon in the air, makes air polluted. So, the reason to use nonconventional energy sources is to reduce the pollution also reduce the fuel problem, one of the solutions to this is Arduino based hybrid power auto cycle. The existing system of the electric bicycle is not charging the battery itself also using only solar source makes it cost so the solution to this is using a hybrid power supply. We can charge the battery itself at least cost as compared to single solar panel source bicycle. Solar assisted bicycles are modification of normal bicycles and driven by solar energy and dynamo. They are suitable with both city and country roads. These bicycles are cheaper, simple in construction and can be widely used for short distance traveling. The operating cost per kilometre is minimal i.e. Rs.0.70/km. They have fewer components, can be easily mounted or dismounted, thus less maintenance. In short, following are the various features of hybrid power bicycle [10]. They are Eco-friendly and pollution free, as they do not have any emissions. Moreover, they are noiseless and can be recharged.

9) In this paper, a sensor fusion algorithm is proposed for electric bicycles to accomplish power-assist function without using torque sensors. The sensor fusion is observer based and uses outputs from the wheel encoder and a 6 axis inertial measurement unit to estimate the longitudinal acceleration of the bicycle and the slope angle of the road. It is mainly based on the kinematic model that describes the time varying characteristics of the gravity vector in a moving frame. By exploiting the structure of the observer model, convergence of the estimation errors can be easily achieved by selecting two sub-gain matrices in spite of the time-varying characteristics of the model. The fusion results allow one to conduct mass compensation, gravity compensation and friction compensation for power assist purposes. With the compensations, riding the power assist bike on hills is similar to riding a conventional bicycle on the level ground regardless the weight increase by the battery and the motor. With the algorithm, one can replace the expensive, bulky torque sensors by low-cost, compact IMU sensors and wheel encoders to achieve power assist function. The sensor fusion algorithm is observer based. A systematic procedure to construct the observer is provided. Although the observer model is time-varying and is fifth-dimensional, by exploiting the model structure, the convergence of the estimation errors can be guaranteed by properly choosing two low-dimensional constant gain matrices. The performance of the sensor fusion algorithm and the power-assist function is validated via a road test. With power assist, the magnitude of the rider's EMG signal is significantly reduced compared to the pure manual pedaling case [11]. The results in this study can be directly applied to power assist other manual-driven vehicles such as wheelchairs.

10) Electric Power Assisted Bicycle (EPAC) is becoming the transport and fitness tools that people pursue because of its green, healthy and economical characteristics. Compared to the conventional electric bike, EPAC not only reduces the burden on the rider, but also maintains the original bicycle characteristics. Nowadays, there is few study of the control approach adaptive to road slope and load for EPAC. This paper proposes a new control approach adaptive to load and road slope for EPAC based on disturbance observers, which can estimate the road slope and bicycle body load by processing the bicycle speed signal and pedal force signal. Accordingly, the motor assisted-power ratio is adjusted in real-time to achieve the optimal assisted-power. As a result, the rider will get better riding experience. The simulation results demonstrate that the proposed control approach is highly effective in various riding conditions. By only processing signals of the motor's torque and speed, the adaptive control can be implemented at low cost. This paper presented a series of comparative simulation results to prove the controller's performance in

some extreme cases [12]. The simulation results and analysis demonstrated that the proposed controller has significant effectiveness and high control performance.

11) The market for electric bikes, scooters and bicycles is growing. There are numerous brands of E-bikes emerging locally. All most all incorporate a rear wheel BLDC (Brushless DC) hub motor; lead acid battery pack, a light weight chassis, and a controller. The Vehicle achieves average speed of 30-
50km/hr, range of 70km/charge. The other drawback is the long charging time of 6-8 hrs and short lifespan of battery pack i.e. around 2 years. Considering these limitations authors are modifying the existing design of an electric bike which will give a better performance with the use of a hybrid system of battery and super capacitor. The authors in this paper have tried to address the drawbacks observed in e-bike operations and have presented the results of their experimentations. Super-capacitor modules are used to provide the high current required during starting and acceleration, and eventfully will help increasing lifespan of battery. A secondary source, like regenerative braking or a small solar panel module could be availed on board so as to charge battery/ super capacitor. IC engines had dominated and revolutionized the last century and have been through a significant transformation from their earlier less efficient designs. Comparatively, E-bikes are newer in market and have started to gain attention of innovators and engineers since a decade. With more and more advancement in battery technology, electric vehicles offer a prominent future in transportation. With incorporation of super capacitors the life of battery has been increased. With modification of design using advanced controller, better motor, other subsequent improvements implemented in the design, the speed of vehicle is increased considerably. However with more professionalism and a robust chassis, it is possible to increase the speed further. A small on board solar panel could charge the super capacitor through an auxiliary battery. The solar panel will also help extending the range of the bike in addition to the regenerative braking system [13]. So even if the bike is parked somewhere where there is no charging facility, a sheer standing bike is getting charged up for the solar panel.

12) The paper focuses on using the BLDC motor as electrical bike drive. As of today on the market there are already different methods of controlling electrical motor of a bike. The most common is setting the motor's speed with a lever mounted on handlebars. Controlling motors torque instead of speed makes new principle of how the drive works. Proposed method of control is based on controlling the motor torque in such a way that allows the user to set a desired torque value keeping the force on bike pedals constant. This article covers different methods of

Chapter 3

METHODOLOGY

3.1 Mechanism of Operation

The basic idea is to attach a motor to the cycle for its motion. A motor that is powered by a battery and that can be switched on during difficult terrains and switched off and pedal to get the battery re-charged during motion in a flat terrain. The idea came into our mind as different stages of project planning, firstly we wanted to implement a simple moving system so the projection of cycle as a system came into our mind, and second stage was adding a necessarily useful component into it that can be beneficial in the future and for common people, falling into the current trend was that of hybrid system so we ended up planning to assemble a motor unit into the cycle drive. There were many issues that came up while making such a system major one of them being the power of the motor to be used, since no such previous systems were made, we could not predict the type of motor which we should go for. Second thing being the weight factor, the addition of extra weight on to the system, which can cause discomfort to the rider while normal pedalling. Third was the type of battery to be used, we should go for a battery that has longer life, economically viable, and also has less maintenance issues [15]. Fourth issue was that self-recharging a battery with a motor alternator unit that too with the simple cranking motion of the cycle was not viable, we had to utilize a mechanism that can come in handy here and that was by using the flywheel rotation technique.

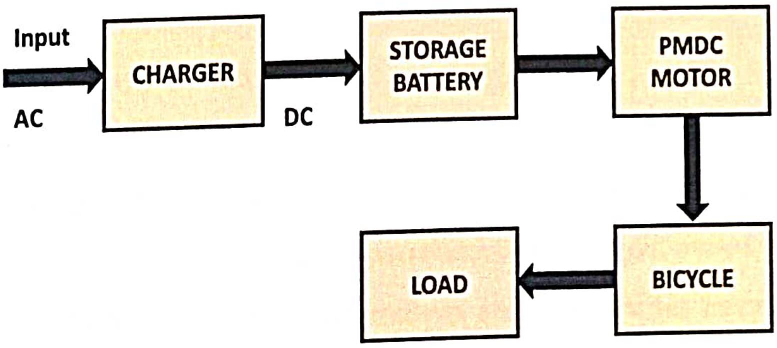

Fig. 3.1: Block Diagram for Electric Powered Bicycle

3.1.1 Mechanical design

The basis of this paper is to construct a system for an electric bike. There are many key components within the block diagram. It consists of a battery, a motor controller, a Hub motor

[16]. The controller is used to trigger the functions for increasing speed, keeping the speed constant, and turning off the motor. The battery block is interfaced with the motor controller block. The motor controller controls all the functional capabilities and is the central component of the system. The basic requirement for the control is to regulate the amount of power applied to the motor, especially for DC motors. The motor controller can be adjusted to synchronize with other brushless motors. The control allows the battery to interface with the motor to be bidirectional which can supply and receive power. Software is provided with the controller so that it can adjust the setting and operations for several of the controller's functions.

3.2 Energy Analysis

Previous studies provided an insight into the average daily consumption of an average male as 2440 kcal, this is about 119W of power in, 10.299MJ or 2861Wh of energy every single day. This is approximately the same amount of energy stored in the typical car battery (2400Wh). The primary fuel used in the production of human power is consumed food. The human body utilizes energy stored in the chemical bonds of consumed compounds such as carbohydrate, proteins, fats and fibre to fuel metabolic processes. These processes include basal metabolic function that sustain life, and advance metabolic function used during physical activities [16]. Food energy is commonly measured in the empirical units of Kilocalories (Kcal) or food calories (C), 1Kcal is equivalent to 1C. In the metric system, is measured in Joules, where 1C is equivalent to 4184J.

3.3 Design Analysis

3.3.1 General design considerations

Generally, the design of this system depends primarily on the ratings of the DC permanent magnets which produce the DC and the required output power. The output power to be produced affects the dimensioning as well as the input parameters like torque, speed, etc. In light of the above constraints, the following design considerations and assumptions have been made for this project design

1. **Sizing and economic considerations:** This system is design to compact in consideration of the power requirement as well as reduction in the cost of fabrication. For affordability, the device is relatively small.

2. **Safety Considerations:** This system is design in such a way that women and children can use it for sustained period of time. It preserves the safety of our immediate environment from noise and air pollution because it's noiseless and smokeless. Stability of the unit was also considered to ensure that the equipment remains upright at all time, i.e. it should not drift or bend to one direction and it should remain stationary.
3. **Ergonomics:** The ergonomics aspect has to do with optimizing the physical contact between human and the equipment [17]. Four important areas of bike ergonomics are usually considered:
    - The strain of the arm and shoulder
    - The muscle support and the position of the lower back
    - The work of proper pedalling
    - The crank length
4. **Technological consideration:** The design of this system is well considered in such a manner that it can be produced within the technology of our immediate environment.

3.3.2 Frame design

It is the skeleton of the vehicle which acts as the back bone of the vehicle and supports and unitizes the body parts of the vehicle. It also provides good handling and safety. A vehicle such as an electric vehicle draws an advantage if it is light in weight. The Frame of the vehicle must be designed such that it must be able to accommodate the battery pack. The vehicle draws its main structural rigidity from the frame and it's supporting members on which all components are mounted. One of the key elements of the design process of objects under cyclical changing loading is the knowledge of service load history. Bike frames encounter a complex set of stresses which in most cases cannot be calculated by hand [18]. Therefore, in designing a frame, engineers usually make use of an older design which has proven reliable as a starting point.

Frame Dimensions:

To ensure the safety of the user and promote efficient cycling, the dimensions of the bike and cyclist must be taken into account, along with the amount of lateral and vertical clearance needed, in the planning and design of bicycle facilities. The dimensions of a typical bicycle are a handlebar height of 0.75 - 1.10 m (2.5 - 3.5 ft.), handlebar width of 0.61 m (2 ft.), and bicycle length of 1.5 - 1.8 m (5 - 6 ft.). They often provide little traction. The general dimensions adopted for the design was (1200 x 200 x 860) mm.

3.4 System Force Torque and Power Input

This system is designed assuming the average mass of 65kg and pedalling time as 60mins. From reviewed literatures, the pedal input force, torque and power can be computed as below:

Input force

$$F = \frac{mv}{t} \tag{3.1}$$

Input Torque

$$T = F \times R \tag{3.2}$$

Input Power

$$P = \frac{2\pi NT}{60} \tag{3.3}$$

Where m = mass in Kg, v= velocity in m/s, t= time in seconds,

f= force in newton and N= speed in rpm

Pedal Mechanical Efficiency

Using the volume of oxygen consumed during exercising, the persons overall or gross mechanical efficiency can be computed as follows:

$$\text{power output} = T_1 * 2\pi r * N \tag{3.4}$$

This power output is equivalent to 2.1Kcal/min

$$\text{Pedal power input} = P_{\text{in pedal}} = VO_2/\text{min} * 5\text{kcal}/VO_2 \tag{3.5}$$

Expended Power in the Pedal system = Pout - Pin

$$\text{efficiency} = \frac{P_{out}}{P_{in}} * 100 \tag{3.6}$$

3.5 Slope Angle

The dynamics of a conventional bike system is first considered as shown in Fig. 3.2. From the point of view of control, there are two components of interests: the road load and the transmission mechanism [20]. Under the assumption that the bike system moves straight, the balance of the force acting on the bike yields the road load equations as:

$$\left.\begin{array}{l} \text{Longitudinal: } F_R - F_F - F_d - (M+m)g\,sin\theta \\ \text{Rear wheel: } \frac{T}{N} - B_{wheel}\omega - F_R R = I\alpha \\ \text{Front wheel: } F_F R_{wheel} - B_{wheel}\omega_{wheel} = I\alpha \end{array}\right\} \tag{3.7}$$

Where the parameters utilized for the model description are defined in Table I. The subscript i=F, R denotes the front and rear wheels, respectively.

Combing the road load equations, (3.7) can be rewritten as

$$T = (2I + MR^2) + 2B_w\omega + F_d R + R(M + m)g\sin\theta$$

$$= J_{Bike}\alpha + B_{Bike}\omega + T_{load} \qquad (3.8)$$

According to (3.8), a block diagram description of the bike system is given in Fig. 3.3. The different power assistance modes can then be designed for different riding and pedalling conditions.

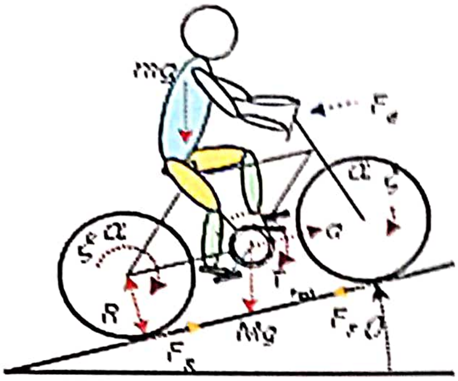

Fig. 3.2: Free-Body Diagram of Bike System

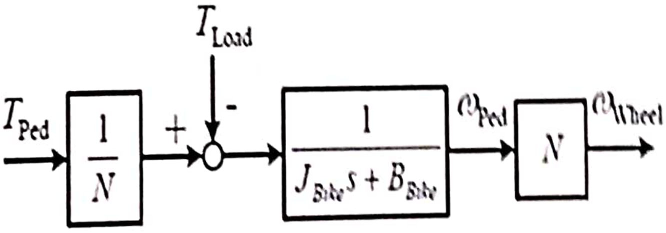

Fig. 3.3: Equivalent Block Diagram of Bike System

Table 3.1: Parameters in bike system

Symbol	Quantity
M,m	Mass of bike and cyclist, respectively(Kg)
G	gravitational acceleration(m/sec^2)
R_{Wheel}	radius of wheel(m)
B_w	damping coefficient of wheel
θ	slope angle(degree)
N	speed ratio of transmission system(rpm)

F_i, F_d	frictional force(n/m), wind resistance (ohm)
a, α	longitudinal and angular acceleration(radiance/sec^2)
ω_{wheel}	angular velocity of wheel
J_{Bike}, B_{Bike}	equivalent moment of inertia and damping coefficient
T_{load}	load torque(nm)

3.6 Gear Ratio

The gear ratio is the ratio of the angular velocity of the input gear to the angular velocity of the output gear. The gear ratio can be calculated directly from the number of teeth on the gears in the system. This system is made up of 2 stage gear systems. The teeth on gears are designed so that the gars can roll on the chain link smoothly without slipping [21]. The number of teeth on gear is proportional to the radius of its pitch circle, which means that the ratios of the gears' angular velocities, radii and number of teeth are equal. Mathematically

$$\frac{\omega_A}{\omega_B} = \frac{R_B}{R_A} = \frac{N_B}{N_A} = \frac{D_B}{D_A} \qquad (3.9)$$

where ω_A, ω_B = angular speed (ohm) of sprocket A and B respectively

R_A, R_B= Radius (m) of sprocket A and B respectively

N_A, N_B = Number of teeth on sprocket A and B respectively

D_A, D_B = Diameter (m) of sprocket A and B respectively

3.7 Flywheel Design

Flywheels are designed to store and release kinetic energy. A Flywheel is disc-shaped, and true to its weight on all sides and locations of the disk. The flywheel is designed to provide a steadier flow of momentum. The size and weight of the flywheel will determine the amount of energy that can be produced from peddling the bike. The mechanical advantages of using a flywheel is that its energy output is consistent and, depending on the size of the flywheel, it is able to store and release great amounts of energy even after the peddling has ceased. The kinetic energy stored in the flywheel is given as:

$$KE = \frac{1}{2} * I * \omega \qquad (3.10)$$

Where, I = polar moment of inertia

ω = angular velocity of the flywheel

Two types of flywheel are available: Heavy and light flywheel

a) **Heavy Flywheel** will take much more effort to get started but will be able to provide the steadiest flow of energy once the heavy weighted disk is in motion. The disadvantage in using a heavy flywheel to power a mechanical device is the individual peddling the bicycle would also have a hard time getting the wheel's momentum engaged and would require more energy input than is required.

b) **Light Flywheel** will be easy to engage through peddling power. The amount of momentum is not as great as a heavier flywheel but will be sufficient enough to rotate the pulley of the DC permanent magnet without causing much stress on the individual. A flywheel weighing about 25-35 pounds is light enough for an individual to mechanically power.

In the light of the above, the light flywheel scored higher than the heavy flywheel [21]. Because the aesthetics of the drive is not crucial to the appearance of the design project in general, the use of the light flywheel for the final design is chosen over the use of the heavy flywheel.

3.8 Belt Selection

There are lots of factors to be considered when selecting the type of belt to be used;

- The speed of the driving or driven pulley
- The power to be transmitted;
- The centre distance between pulleys
- Speed ratio
- Service condition

Considering the above, timing-belt will be used [22]. According to Khurmi and Gupta (2012), in analysing, the following design equations are used to generate the parameters needed for the belt design;

Length of the belts:

$$L = \frac{\pi}{2}(D + d) + 2C + \frac{(D-d)^2}{4C} \qquad (3.11)$$

Belt Centre Distance:

$$C = 2\sqrt{(D + d)d} \tag{3.12}$$

Where, L = length of the belt

D= diameter of big pulley in m

d = diameter of small pulley in m

C = centre to centre distance in m

Angle of lap (arc of contact) in degree

$$\theta = (180 - 2\alpha)\frac{\pi}{180} \tag{3.13}$$

Belt speed

The velocity at which a belt travels may be expressed as:

$$V = \frac{\pi DN}{60} \tag{3.14}$$

V= velocity in m/s

N = speed in rpm

Belt tension:

When a belt is fitted around pulleys, it is given an initial tension which only exists while the system is at rest. Since the belt continuously runs over the pulleys, some centrifugal force is caused whose effect is to increase the tension on both the tight as well as the slack sides [22]. The belt tension can be obtained from the following relationship.

$$P = (T_1 - T_2)V \tag{3.15}$$

$$2.3 log\frac{T_1}{T_2} = \mu\alpha \tag{3.16}$$

Where: P = power of motor

T_1 = Tension on the tight side (resisting side) in newton

T_2 = Tension on the slack side (pulling side) in newton

V = Velocity of the belt in m/s

μ = coefficient of static friction in newton

α = contact angle in degree

3.9 Chain Drive Selection

In order to select a chain drive, the following essential information must be known:

- The power to be transmitted
- The speed of the driving and driven pulleys

To calculate the:

Pitch of the chain

$$P = \frac{2\pi(R+r)}{T_1+T_2} \tag{3.17}$$

Centre distance

$$X = \frac{D+d}{2} + 30 \tag{3.18}$$

Length of chain

$$L = \frac{P}{2}(t_1 + t_2) + 2X + \frac{(\frac{P}{2}cosec\frac{180}{11} - \frac{P}{2}cosec\frac{180}{12})}{X} \tag{3.19}$$

Which can further be simplified as

$$L = Y + 2X + Z \tag{3.20}$$

where, t_1 = Number of teeth on the driver sprocket

t_2 = Number of teeth on the driven sprocket

P = Pitch of the chain

X = Centre distance in m

$$Y = \frac{P}{2}(t_1 + t_2)$$

$$Z = \frac{(\frac{P}{2}cosec\frac{180}{11} - \frac{P}{2}cosec\frac{180}{12})}{X}$$

3.10 Shaft Design

The shaft used for this design was designed based on a shaft subjected under combined bending and twisting moment [23]. The following parameters were assumed for the design:

Maximum allowable working stress = 63Mpa; Maximum shear stress = 42Mpa. Torque on the flywheel is equal to that on the small sprocket.

Let T_1 = maximum tension (n) on the flywheel (pulley C), T_2 = tension (n) on the slack side of the flywheel, T_3 = Tension (n) on the tight side of the chain on sprocket, T_4 = Tension (n) on the slack side of the chain

Vertical load on the flywheel, $W_C = T_1 + T_2$ (3.21)

Vertical load on compound sprocket, $W_D = T_3 + T_4$ (3.22)

Torque acting on the flywheel, $T = (T_1 - T_2)\ W_C$ (3.23)

Since the torque on both flywheel and sprocket is same,

$$T_3 - T_4 = \frac{T}{R_D} \tag{3.24}$$

and

$$\frac{T_3}{T_4} = \frac{T_1}{T_2}$$

Horizontal load on shaft due to flywheel = 0

Horizontal load due to sprocket = 0

Reaction on the bearing support

Considering the vertical load on flywheel

$$R_{AV} + R_{BV} = [T_1 + T_2] \tag{3.25}$$

$$R_{BV}x0.15 = T_1 + T_2x0.075$$

Bending moment at A and B

$$M_{CV} = R_{AV} * 0.075 \tag{3.26}$$

$$M_{DV} = R_{BV} * 0.038 \tag{3.27}$$

Maximum bending moment, $M = M_C$

Let d = diameter of shaft in m

Equivalent twisting moment

$T_e = \sqrt{(M^2 + T^2)}$ in nm (3.28)

and

$T_e = \frac{\pi}{16} x \tau x d^3$ (3.29)

Equivalent bending moment

$M_e = \frac{1}{2}\left[M + \sqrt{M^2} + T^2\right] = \frac{1}{2}[M + T_e]$

and

$M_e = \frac{\pi}{32} x \sigma_b x d^3$ (3.30)

3.11 Bearing Selection

Bearing dimensions have been standardized on an international basis. The dimensions are a function of the bearing bore and the series of bearing: Extra light (100); Light (200); Medium (300); Heavy (400) [24]. In order to select the correct bearing for the design, the basic dynamic radial load was calculated, multiply by the service factor. The mathematical relationship for the bearing selection is presented below:

Service life

L_H= *Years x 1 day x hrs/day* (3.31)

Life of bearing in revolutions

L= 60 x speed x L_H (3.32)

L_H= life hours

3.12 Freewheel

A freewheel mechanism on a bicycle allows the rear wheel to turn faster than the pedals. If there is no freewheel on a bicycle, a simple ride could be exhausting, because one could never stop pumping the pedals [33]. And going downhill would be downright dangerous, because the pedals would turn on their own, faster than one could keep up with them.

Power Train of a bicycle: The power train of a simple bicycle consists of a pair of pedals, two sprockets and a chain. The pedals are affixed to one sprocket the front sprocket, which is mounted to the bike below the seat. The second sprocket is connected to the hub of the rear wheel. The chain connects the two sprockets. When you turn the pedals, the front sprocket turns. The chain transfers that rotation to the rear sprocket, which turns the rear wheel, and the bicycle moves forward. The faster you turn the pedals, the faster the rear wheel goes, and the faster the bike goes.

Coasting: At some point when going downhill, for instance speed is high enough so that the rear wheel is turning faster than the pedals. That's when coasting: we stop working the pedals and let the bike's momentum keep moving forward. It's the free wheel that makes this possible. On a bicycle, instead of being affixed to the wheel, the rear sprocket is mounted on a freewheel mechanism, which is either built into the hub of the wheel a "free hub" or attached to the hub, making it a true freewheel.

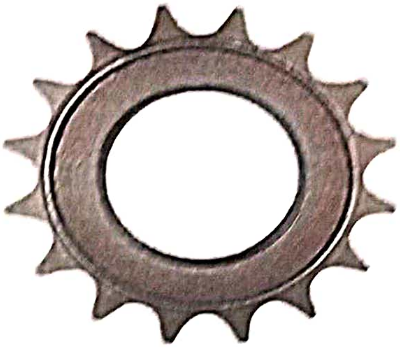

Fig 3.4: Freewheel

Now when forward movement is required, the pawl acts like a hook and gets locked with the teeth called ratchet and transmits the torque. The complete mechanism is called ratchet and pawl mechanism.

But when pedal is reversed, it falls back and becomes "free". A spring prevents it from falling permanently. This is the reason why you hear the distinct "click-click" sound when you reverse pedal. Also, there are multiple "pawls" placed along the circumference too.

3.13 Battery Selection

The battery is selected based on the amount of time wanted to operate the system at full load. Generally, the relationship between the energy stored in the battery and the time of discharge is given by the expression below:

$$\text{Power} = \text{Voltage} \times \text{Current}\ [\text{Watts}] \tag{3.33}$$

$$\text{Energy} = \text{Current} \times \text{Time}\ [\text{Watt-hr}] \tag{3.34}$$

The following equations to calculate the range from amperage and voltage:

$$Ah\ (Amp\ hours) \times V\ (volts) = Wh\ (Watt\ hours) \tag{3.35}$$

Select a 48V, 10Ah battery with 480 Wh.

$$P\ (power) = Work / t\ (time) \quad \text{in watt} \tag{3.36}$$

$$P \times t = Work = Force \times distance \tag{3.37}$$

$$Force = mass \times acceleration \quad \text{in n} \tag{3.38}$$

$$Distance = Wh / Force \quad \text{in m} \tag{3.39}$$

Electric bicycles are often restricted to a speed of 30 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 480Wh battery can roughly provide a range of total 55 km.

Table 3.2: Available Battery Types

POWER TRAIN TYPE	ADVANTAGES	DISADVANTAGES
Lead-Acid (sealed)	• Inexpensive and simple to manufacture • Mature, reliable and well-known technology • Low self-discharge: the self-discharge rate is among the lowest in rechargeable batteries. Capable of high discharge rates.	• Not to be stored in a discharged condition • Low energy density: poor weight to energy density • Environmentally unfriendly: the electrolyte and the lead content can cause environmental damage.
Lithium-Ion	• Highest energy density to weight ratio • Eliminates need for periodic care for a long life • Has no memory effect • Achieves a better cost-performance ratio for battery packs in series than for single cell • Is arguably better for the environment, from a raw materials viewpoint, to other	• All lithium-ion technologies require a protection circuit to prevent overheating • Can damage easily by over charge or discharge

	options • Li-ion-Cobalt is the most developed Li-ion technology, with flexible shape options	
NiCad	• Fast and simple charge even after prolonged storage • High number of charge and discharge cycles if properly maintained • Good load performance: the NiCad allows recharging at low temperatures • Long shelf life in any state-of-charge • Forgiving if abused the NiCad is one of the most rugged rechargeable batteries • Economically priced: the NiCad is the lowest cost battery in terms of cost per cycle. • Available in a wide range of sizes and performance options	• Relatively low energy density when compared with newer systems • Memory effect the NiCad must periodically be exercised to prevent memory • Environmentally unfriendly the NiCad contains toxic metals • Some countries are limiting the use of the NiCad battery • Has relatively high self-discharge needs recharging after storage
NiMH	• 30%-40% higher capacity over a standard NiCad. The NiMH has potential for yet higher energy densities. • Less prone to memory than the NiCad. Periodic exercise cycles are required less often • Environmentally friendly: contains only mild toxins; profitable for recycling • NiMH generates more heat during charge and requires a longer charge time than the NiCad • About 20% more expensive than NiCad	• Limited service life—shallow rather than deep discharge cycles preferred • Repeated discharges with high load currents reduce the battery's cycle life • High self-discharge: NiMH has about 50% less stored shelf life than NiCad • Performance degrades if stored at elevated temperatures • High maintenance: requires regular full discharge to prevent crystalline formation

Based on the information listed in Table 3.2, Lead acid/SMF battery and Li-ion battery is selected.

3.13.1Sealed maintenance free (SMF) battery

Sealed Maintenance Free batteries are widely used where minimal maintenance and space requirements are the main considerations. In UPS systems, it is used because of its maintenance free and eco-friendly features. SMF batteries do not require water and acid top up and are totally maintenance free. There is no water loss during the charge- discharge cycle and the battery works on the oxygen recombination principle [26]. SMF battery is also called as Valve Regulated Lead Acid or VRLA battery.

SMF battery is totally maintenance free and has longer cyclic life, thus compensating the initial higher cost. One of the important aspects of battery life in relation to the use of equipment is the cut off voltage set in the equipment. For example in inverter systems using high current batteries like 150Ah, a cut off voltage less than 10.5 volts can shorten the life of the battery. If the cut off voltage is set as 11.5 volts, it will increase the battery life since the battery is not entering into the deep discharge state.

Fig 3.5: SMF battery

In the SMF battery, the chemical recombination occurs in the Positive plate as per the following equation

$H_{20} = \frac{1}{2} O_2 + 2H+ + 2e^-$

In the Negative plate, the reaction occurs as

$2Pb + O_2 = 2PbO$

$PbO + H_2SO_4 = PbSO_4 + H_2O$

$PbSO_4 + 2e- + 2H+ = Pb + H_2SO_4$

During the chemical reaction, oxygen evolved from the positive plate recombines at the negative plate and suppress the formation of hydrogen. This prevents gas accumulation inside the battery. So SMF Battery is clean and Eco-friendly [26]. Moreover there is no free acid or electrolyte in the battery, so that the battery can be placed in any position. There is an Absorbed Glass Mat or AGM inside the battery that holds the acid. The acid is thus in an immobilized form as gel. In order to avoid excess pressure and battery explosion, vent valves are provided to release the pressure inside the battery.

The important features of SMF battery are:

1. It is compact and can be oriented in any position like vertical, horizontal etc.
2. There is no fume or smell from the battery since the acid is in gel form.
3. The battery can be installed in the equipment prior to transportation since there is no leakage or water spill during transportation.
4. More economical than any other forms of battery.

In order to increase the life of battery, it is necessary to monitor the battery performance constantly. Here are some tips to optimize the battery performance.

1. The SMF battery should be placed in well-ventilated area to avoid high temperature environment. With each 10 degree rise in air temperature, the float life reduces to half. If the battery is installed in equipment, it is necessary to isolate it from heat generating components like transformer.
2. In order to prevent deep discharge, it is necessary to set the cut off voltage to 11.5 volts in 12 volt battery and 4.5 in 6 volt battery.
3. It is necessary to prevent no load battery drain [26]. The additional components of the equipment such as sensors, displays and indicators consume power in the no load condition. So if the equipment is not provided with automatic charging, this power loss leads to deep discharge.
4. Boost cum float charging is suitable for SMF battery. If the power failure is frequent, the battery should be charged immediately to acquire full charge before the next power failure.
5. If there is any problem such as low backup time, battery heating, low terminal voltage even after continuous charging develops, the battery should be attended immediately.
6. If the equipment is not using for long time, it should be charged once in every week. If the battery is allowed to charge and discharge frequently, its life can be extended to 3-5 years.

3.13.2 Lithium-ion battery

Li-ion batteries, as one of the most advanced rechargeable batteries, are attracting much attention in the past few decades. Li-ion batteries are considered the powerhouse for the personal digital electronic revolution starting from about two decades ago, roughly at the same time when Li-ion batteries were commercialized.

A Li-ion battery is constructed by connected basic Li-ion cells in parallel (to increase current), in series (to increase voltage) or combined configurations. Multiple battery cells can be integrated into a module. Multiple modules can be intergrade into a battery pack [27]. The electrodes are isolated from each other by a separator, typically micro porous polymer membrane, which allows the exchange of lithium ions between the two electrodes but not electrons. In addition to liquid electrolyte, polymer, gel, and ceramic electrolyte have also been explored for applications in Li-ion batteries. Figure 4illustrates the basic operating principle of a typical Li-ion battery cell.

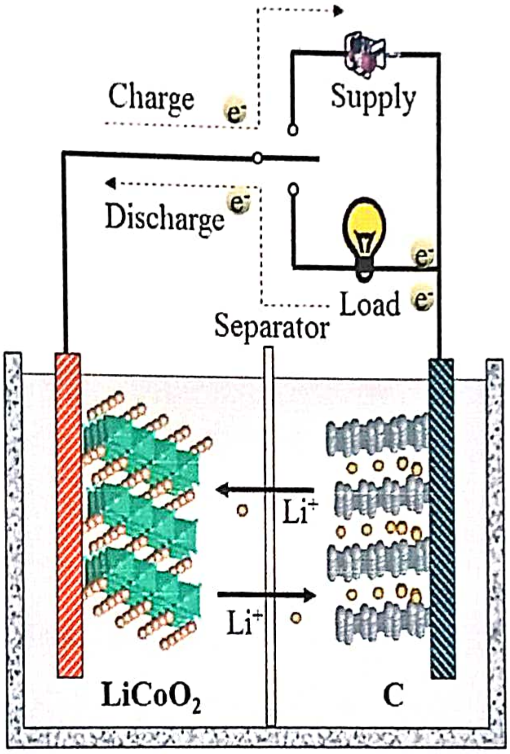

Fig 3.6: Illustration to show the basic components and operation principle of a Li-ion cell

The commercial cells are typically assembled in discharged state. The discharged cathode materials (e.g.,$LiCoO_2$, $LiFePO_4$) and anode materials (e.g., carbon) are stable in atmosphere and can be easily handled in industrial practices. During charging process, the two electrodes are connected externally to an external electrical supply. The electrons are forced to be released at the cathode and move externally to the anode. Simultaneously the lithium ions move in the same direction, but internally, from cathode to anode via the electrolyte. In this way the external energy are electrochemically stored in the battery in the form of chemical energy in the anode and cathode materials with different chemical potentials [27]. The opposite occurs during discharging process; electrons move from anode to the cathode through the external load to do the work and Li ions move from anode to the cathode in the electrolyte. This is also known as "shuttle chair" mechanism, where the Li ions shuttle between the anode and cathodes during charge and discharge cycles.

Tips for extending life cycle of the battery:

Tip 1 – Try not to discharge the battery below 20%. Deep discharge makes the battery too difficult to use and reduces its capacity in future. A lithium battery starts to oxidize, which has a negative effect on capacity as well as battery life. In the case of switching off (e.g. in winter), it is recommended that the battery be fully charged at least once every 90 days.

Tip 2 – Do not charge the battery immediately after riding. The battery should cool down before charging. If we start charging a heated battery, it will not be able to cool down at all, and degradation will be much faster.

Tip 3 – Do not fully charge the battery if it is not necessary. When charging the battery above 80% of its capacity (around 40V), the internal resistance of the battery increases, the battery heats up more and this significantly accelerates the degradation process.

Tip 4 – Avoid extreme temperatures. High temperatures and frost affect performance and shorten battery life. Never store the battery outside where it will be exposed to temperatures below 0°C. Similarly, we recommend not storing the battery at temperatures above 30°C. Furthermore, avoid long parking under direct sunlight.

3.13.3 Comparison between Sealed Maintenance Free (SMF) battery and Lithium ion battery

Table 3.3: Comparison between SMF battery and Lithium ion battery

Characteristics	VRLA lead acid/SMF	Lithium-ion (LiNCM)
Energy Density (Wh/L)	100	250
Specific Energy (Wh/kg)	40	150
Regular Maintenance	No	No
Initial Cost ($/kWh) - prices are only a market average and estimate	120	600
Cycle Life	1,000 @ 50% DoD	1,900 @ 80% DoD
Typical state of charge window	50%	80%

Temperature sensitivity	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 99% @4-hr rate 92% @1-hr rate
Voltage increments	2 V	3.7 V

3.13.3.1 Life cycle and performance

Lithium-ion has significantly higher cycle life than lead acid in deep discharge applications. The disparity is further increased as ambient temperatures increase [28]. The cycle life of each chemistry can be increased by limiting the depth of discharge (DoD), discharge rate, and temperature, but lead acid is generally much more sensitive to each of these factors.

In the figures below, AGM refers to a lead acid battery.

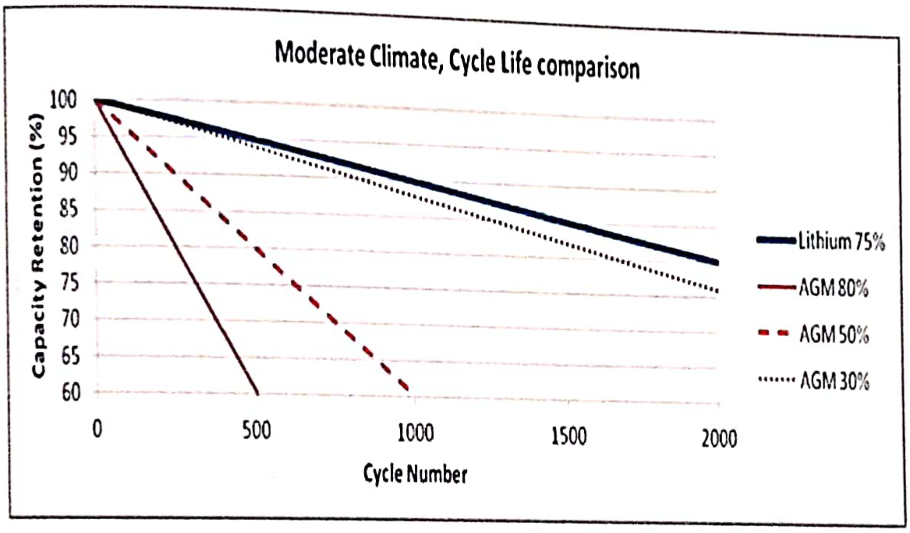

Fig 3.7: Life cycle comparison in moderate climate

In hot climates where the average temperature is 33°C, the disparity between lithium-ion and lead acid is further exacerbated. The cycle life for lead acid (flooded and VRLA) drops to 50% of its moderate climate rating while lithium-ion will remain stable until temperatures routinely exceed 49°C.

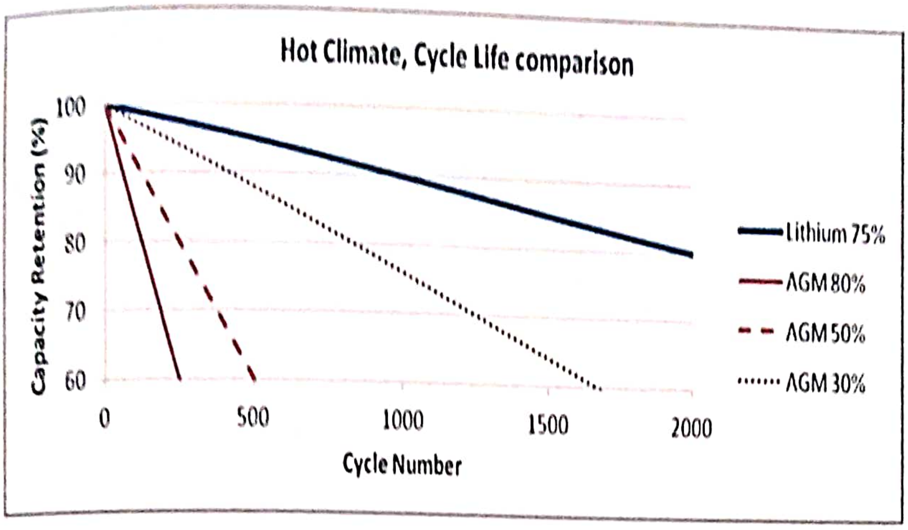

Fig 3.8: Life cycle comparison in hot climate

Analysis indicate that lithium-ion has an 18% higher lifetime cost when compared to lead acid in moderate climates, but is much more cost effective in hot climates [28]. There is a significant area of the world that sees average temperatures high enough to decrease the life of lead acid batteries. A factor not represented in the figure is that the battery systems are often housed in enclosures that see internal temperatures 10°C higher than the air temperature due to solar insolation, which would further decrease the performance of lead acid. The average temperature is also not completely representative of how much time is spent at extreme temperatures where the degradation accelerates in lead acid systems (e.g. one hour spent at 40°C and one hour spent at 20°C has a worse impact on the battery compared to two hours spend at 30°C)

Another critical consideration for lead acid is how long the system will take to discharge. The shorter the discharge period, the less capacity is available from the lead acid battery.

A 100Ah VRLA battery will only deliver 80Ah if discharged over a four hour period. In contrast, a 100Ah lithium-ion system will achieve over 92Ah even during a 30 minute discharge. As shown in the figure below, this condition makes lithium-ion very well suited for applications where full discharge occurs in less than eight hours.

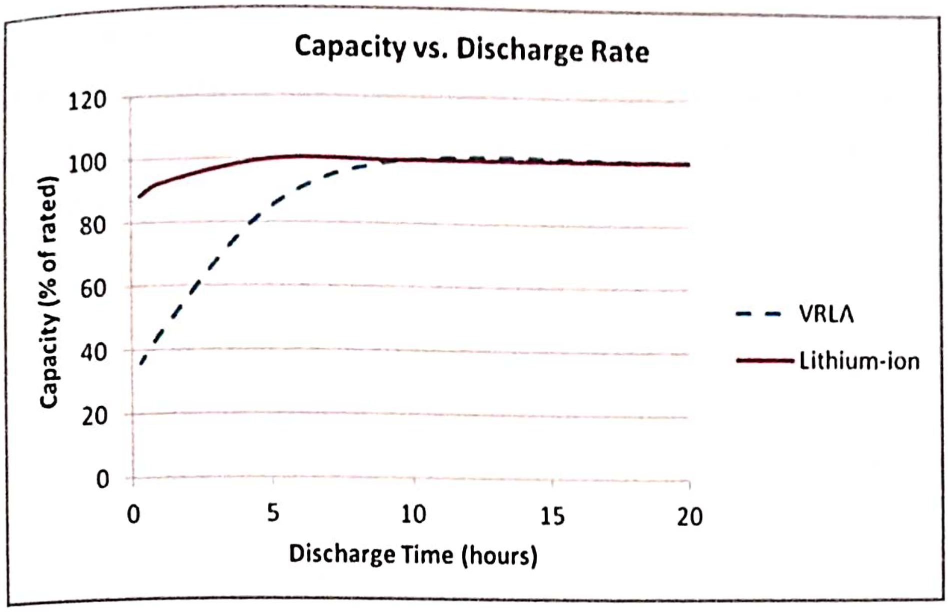

Fig 3.9: Comparison of Capacity vs Discharge rate

3.13.3.2 Environmental impact

Lead acid batteries compare poorly to lithium-ion with regards to environmental friendliness. Lead acid batteries require many times more raw material than lithium-ion to achieve the same energy storage, making a much larger impact on the environment during the mining process. The lead processing industry is also very energy intensive, leading to large amounts of pollution [28]. Although lead is highly hazardous to human health, the manufacturing methods and battery packaging make the human risk negligible.

Lithium is not without its own environmental problems. The major components of a lithium-ion cell require the mining of lithium carbonate, copper, aluminium, and iron ore. Lithium mining specifically is resource intensive, but lithium is only a minor portion of the battery cell by mass, so the aluminium and copper environmental impacts are much more significant. The lithium-ion recycling industry is only in its infancy right now, but the cell materials have shown high ability for recovery and recyclability, so it is expected that lithium-ion recycling rates will rival lead acid.

3.13.3.3 Safety

Lead acid and lithium-ion cells are both capable of going into "thermal runaway" in which the cell rapidly heats and can emit electrolyte, flames, and dangerous fumes. The likelihood and consequences of an event are higher for lithium-ion as it has a higher amount of energy in a smaller volume. Multiple cell and pack safety precautions are taken to prevent trigger events, such as short circuits and overheating, but incidents still occur.

3.13.3.4 Life cycle analysis

A study was performed by Stanford scientists to calculate the carbon footprint of grid-scale battery technologies. To quantify the long-term energetic costs, Barnhart and Benson came up with a new mathematical formula they dubbed ESOI, or energy stored on investment. "ESOI is the amount of energy that can be stored by a technology, divided by the amount of energy required to build that technology," Barnhart said. "The higher the ESOI value, the better the storage technology is energetically."

Of the five battery technologies they researched, Lithium-ion batteries were the best performers, with an ESOI value of 10. Lead-acid batteries had an ESOI value of 2, the lowest in the study [28]. "That means a conventional lead-acid battery can only store twice as much energy as was needed to build it," Barnhart said. "So using the kind of lead-acid batteries available today to provide storage for the worldwide power grid is impractical."

Additionally, the best way to reduce a battery's long-term energetic costs, he said, would be to improve its cycle life – that is, increase the number of times the battery can charge and discharge energy over its lifetime. Lithium-ion was the best at 6,000 cycles, while lead-acid technology is at the bottom, achieving a mere 700 cycles.

3.14 Permanent Magnet Dc (PMDC) Motor

A Permanent Magnet DC motor (or PMDC motor) is a type of DC motor that uses a permanent magnet to create the magnetic field required for the operation of a DC motor. As it is indicated in name of permanent magnet DC motor, the field poles of this motor are essentially made of permanent magnet. A PMDC motor mainly consists of two parts. A stator and an armature. Here the stator which is a steel cylinder, the magnets are mounted in the inner periphery of this cylinder.

The permanent magnets are mounted in such a way that the N-pole and S-pole of each magnet are alternatively faced towards armature. That means, if N-pole of one magnet is faced towards armature then S-pole of very next magnet is faced towards armature. In addition to holding the magnet on its inner periphery, the steel cylindrical stator also serves as low reluctance return path for the magnetic flux. Although field coil is not required in permanent magnet DC motor but still it is sometimes found that they are used along with permanent magnet. This is because if permanent magnets lose their strength, these lost magnetic strengths can be compensated by field excitation through these field coils. Generally, rare earth hard magnetic materials are used in this permanent magnet.

The rotor of a PMDC motor is similar to other DC motor. The rotor or armature of permanent magnet DC motor also consists of core, windings and commutator. Armature core is made of number of varnish insulated, slotted circular lamination of steel sheets.

By fixing these circular steel sheets one by one, a cylindrical shaped slotted armature core is formed. The varnish insulated laminated steel sheets are used to reduce eddy current loss in armature of permanent magnet DC motor. These slots on the outer periphery of the armature core are used for housing armature conductors in them. The armature conductors are connected in a suitable manner which gives rise to armature winding. The end terminals of the winding are connected to the commutator segments placed on the motor shaft. Like other DC motor, carbon or graphite brushes are placed with spring pressure on the commutator segments to supply current to the armature.

The working principle of PMDC motor is just similar to the general working principle of DC motor [29]. That is when a carrying conductor comes inside a magnetic field, a mechanical force will be experienced by the conductor and the direction of this force is governed by Fleming's left hand rule. As in a permanent magnet DC motor, the armature is placed inside the magnetic field of permanent magnet; the armature rotates in the direction of the generated force. Here each conductor of the armature experiences the mechanical force F = B.I.L Newton where, B is the magnetic field strength in Tesla (weber / m2), I is the current in Ampere flowing through that conductor and L is length of the conductor in metre comes under the magnetic field. Each conductor of the armature experiences a force and the compilation of those forces produces a torque, which tends to rotate the armature.

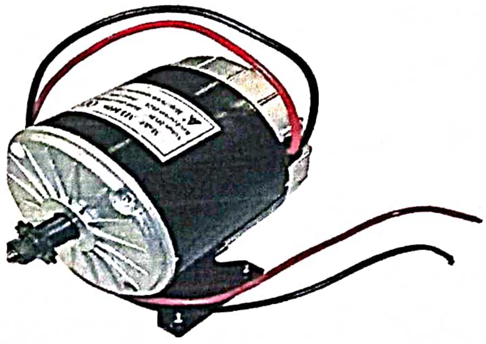

Fig. 3.10: Permanent Magnet DC Motor

Motor Specifications

Voltage: 24V DC

Rated speed: 2650RPM +/- 5%

Rated current: 13.7A

Current without load: 0.7-1.4A

Ambient temperature: -20°C to 45°C

Rated Power: 250W

Advantages of 250W permanent magnet e-bike dc motor are,

- The size of these motors are smaller
- These motors are cheaper
- These motors do not need field windings, and they don't have the copper losses in the field circuit

3.15 Motor Controller

The electric vehicle controller is the electronics package that operates between the batteries and the motor to control the electric vehicle's speed and acceleration much like a carburetor does in a gasoline-powered vehicle [32]. The controller transforms the battery's direct current into alternating current (for AC motors only) and regulates the energy flow from the battery. Unlike the carburet or, the controller will also reverse the motor rotation (so the vehicle can go in reverse), and convert the motor to a generator (so that the kinetic energy of motion can be used to recharge the battery when the brake is applied).

A controller is composed of main chips (microcontrollers) and peripheral components (resistors, sensors, MOSFET, etc) [35]. Generally, there are PWM generator circuit, AD circuit, power circuit, power device driver circuit, signal acquisition and processing circuit, over-current and under-voltage protection circuit inside the controller.

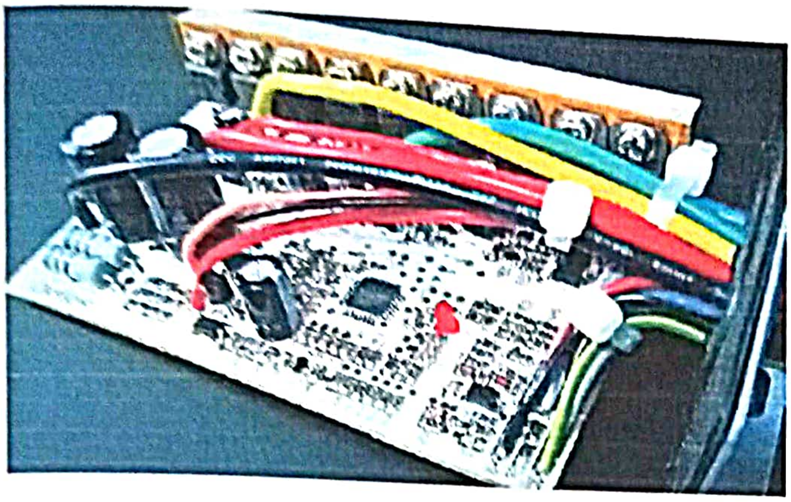

Fig 3.11: Controller circuit board

In the early electric vehicles with DC motors, a simple variable-resistor-type controller controlled the acceleration and speed of the vehicle. With this type of controller, full current and power was drawn from the battery all of the time. At slow speeds, when full power was not needed, a high resistance was used to reduce the current to the motor [32]. With this type of system, a large percentage of the energy from the battery was wasted as an energy loss in the resistor. The only time that all of the available power was used was at high speeds.

Modern controllers adjust speed and acceleration by an electronic process called pulse width modulation. Switching devices such as silicone-controlled rectifiers rapidly interrupt (turn on and turn off) the electricity flow to the motor. High power (high speed and/or acceleration) is achieved when the intervals (when the current is turned off) are short, low power (low speed and/or acceleration) occurs when the intervals are longer.

The PWM outputs a corresponding pulse waveform to the MOSFET drive circuit based on the input of the throttle or PAS. The MOSFET drive circuit controls the turn-on and turn-off of the MOSFET circuit to control the motor speed [35].The under-voltage circuit is to protect the battery from discharging when the voltage is lower than the controller set value, at this time the PWM circuit stops the output. The over-current protection circuit limits the working of the controller, battery, motor at an over higher current.

3.15.1 Functions of motor controller

The core function of an electric bike controller is to take all the inputs from all the electric components (throttle, speed sensor, display, battery, motor, etc.) and then determine what should be signalled in return to them (motor, battery, display).Other multiple protection functions of the controller will be different from the controller's design.

Following are some basic protection functions.

1. ***Over-voltage protection:*** The controller monitors the battery voltage and shut down the motor when the battery voltage is too high. This protects the battery from over-charge.
2. ***Low-voltage protection:*** The controller monitors the battery voltage and shut down the motor when the battery voltage is too low. This protects the battery from over-discharge.
3. ***Over-temperature protection:*** The controller monitors the temperature of the FET(field-effect transistor) and shut down the motor if they become too hot. This protects the FET power transistors.
4. ***Over-current protection:*** Reduce the current to the motor if too much current is being supplied. This protects both the motor and the FET power transistors.
5. ***Brake protection:*** The motor shut down when braking even though other signals taken by the controller at the same time. For example, if the user applies brake and throttle at the same time, the brake function wins.

Fig 3.12: Motor controller

Chapter 4

MOUNTING OF THE COMPONENTS

The components that are discussed in the previous chapter are used to build the electric powered bicycle.

- The 250W PMDC motor is linked with a flywheel using the sprocket, the shaft from flywheel is then linked to the sprocket on the other side with housing. The drive from this sprocket to the multi crank freewheel is attached. The drive from this crank is directly linked with rear wheel sprocket that facilitates its motion. This arrangement is as shown in Fig 4.1

Fig 4.1: View of PMDC motor fixed to the rear wheel of the bicycle

- The SMF batteries are placed on the rear rack of the bicycle. Four 12V SMF batteries are used to power the motor, where two batteries are connected in series and further these two series connected batteries are connected in parallel combination forming a whole of battery producing 24V. The connection of SMF batteries is as shown in Fig 4.4.

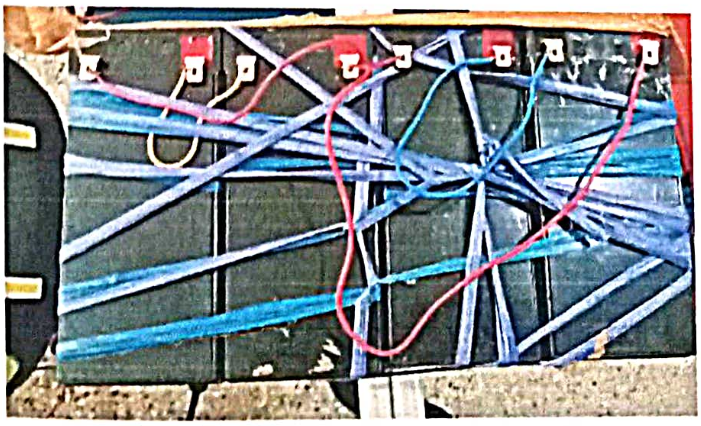

Fig 4.2: SMF battery arrangement

To study the performance of the bicycle when it uses Lithium-ion battery, the motor terminals are connected to the Li-ion battery as shown below

Fig 4.3: Li-ion battery experimentation setup

The batteries are charged using the power charger which is as shown below

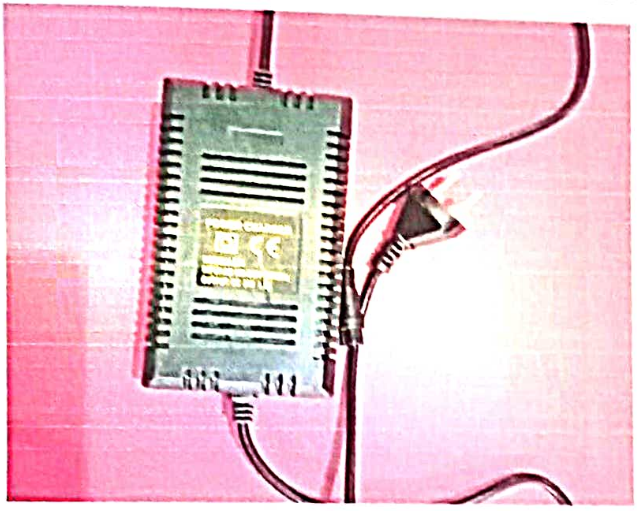

Fig 4.4: Bicycle Charger

- The throttle is fitted to the handle of the bicycle and the gear of the gear can be adjusted. The power from the battery is used by the motor when the throttle is operated. The power utilized depends on the extent to which the throttle is twisted.

The throttle mode is similar to how a motorcycle or scooter operates [30]. When the throttle is engaged the motor provides power and propels you and the bike forward. A throttle allows you to pedal or just kick back and enjoy a "free" ride!

E-bike is equipped with both the throttle and the pedal assist modes. The e-bike can be operated in the pedal assist mode and then get an additional boost by twisting the throttle. E-bikes have a throttle, which may conjure visions of a motorcycle's twist grip, but in reality is usually just a small electric button and also can be fine-tuned like a volume dial between low and full power [31]. Pressing the throttle works just like depressing the gas pedal on your car — no other action is required to accelerate or continue forward movement.

Fig 4.5: Throttle

- The light is placed in the front side of the bicycle between the handle bars and the lock for the bicycle is placed on the crossbar
- The motor is connected to the controller which can be termed as the brain of the electric bicycle as it controls the speed of the motor. The controller used is of 24V and 250W as shown in Fig 4.2.

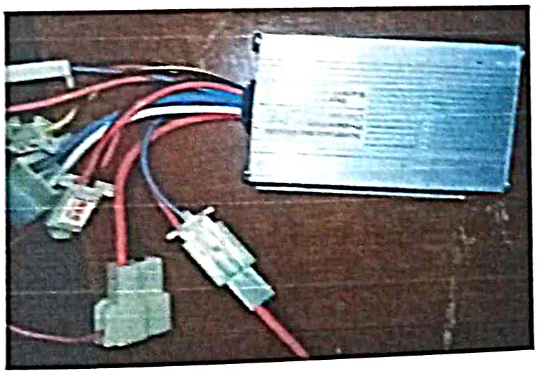

Fig 4.6: 24V, 250W Controller

The controller consists of various wires and the wire types and wire terminal (connector) of the e-bike controller could be different in the different controller design. You need the electric bike controller wiring diagram to ensure the right wiring connections. Most e-bike controller will have these wires motor, battery, brakes, throttle/accelerator or PAS Pedal Assist System (some controllers have both types of wires, some have one of them).Some more wires are found in the advanced controllers, such as Display or speedometer, Three speeds, Reverse, LED light, etc.

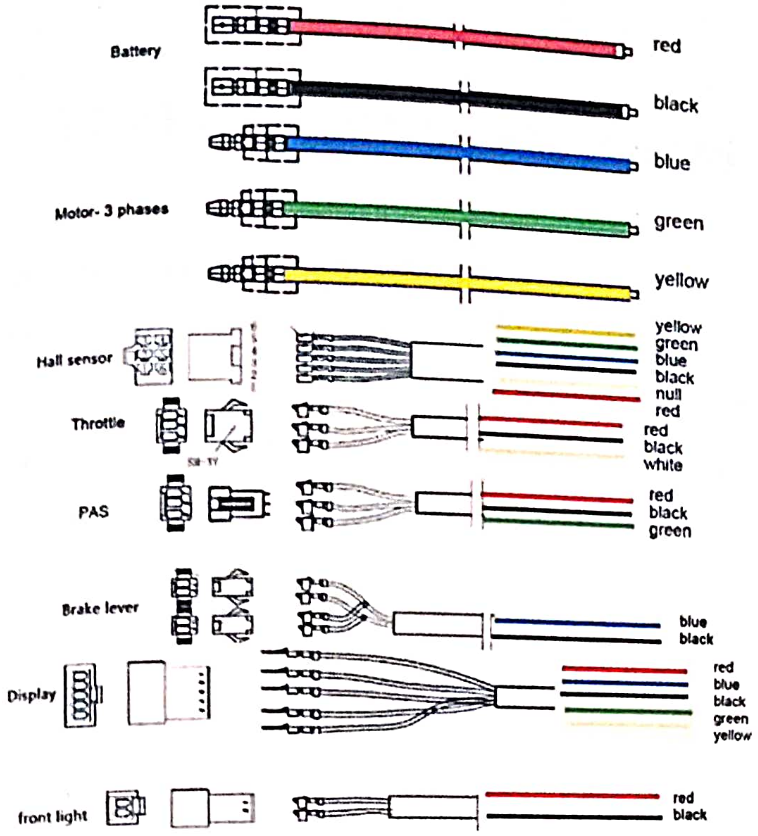

Fig 4.7: Wire specifications of the controller

The above figure shows the wiring in controller. The components such as throttle, brake lever, front light, and hall sensors are connected/linked with the controller as per the wiring specifications shown.

The Fig 4.7 shows the view of bicycle after mounting all the components on it

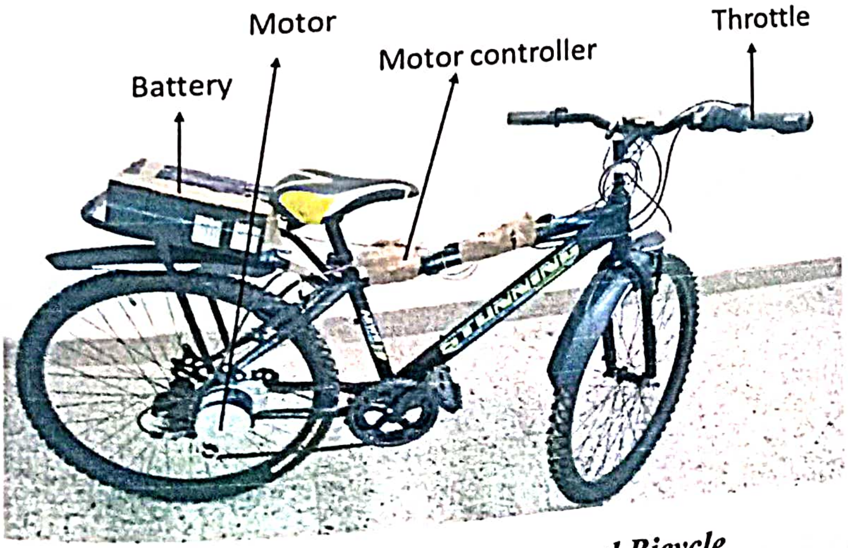

Fig 4.8: View of Electric Powered Bicycle

Chapter 5

EXPERIMENTAL ANALYSIS

The generalized circuit diagram for the electric powered bicycle is shown in Fig 5.1. The controller in whole describes the motor controller connected with throttle and other components. To determine the voltage and current values that are used to rotate the wheel, ammeter and voltmeter should be used. We have used two multi-meters to determine the voltage and current drawn. Fig 5.2 shows the experimentation setup made to conduct the experiment.

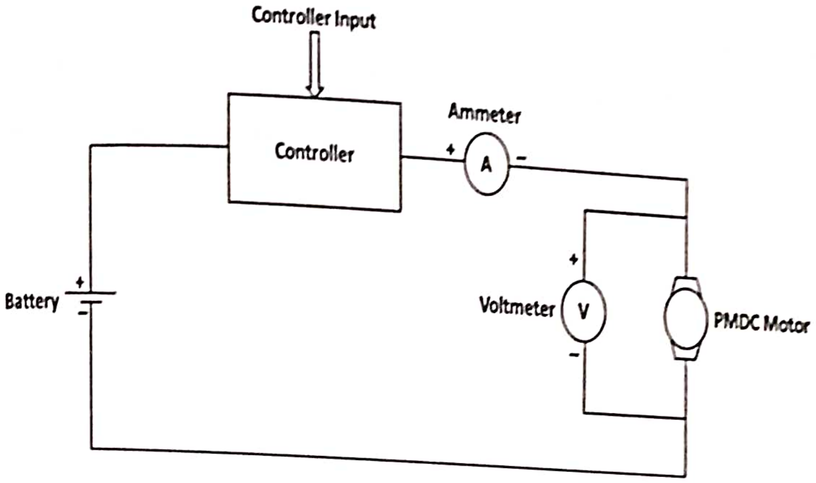

Fig 5.1: Circuit diagram of electric powered bicycle

Fig 5.2: Experimentation setup

Procedure

1. The connections are made as shown in Fig 5.1 where the multi-meters are connected in series with the controller circuit and in parallel with the PMDC motor accordingly. The knob of the multi-meters is kept at the DC point of both voltage (200V) and current (20A)

Fig 5.3: Multi-meter

2. A radium sticker is attached to the tire of the wheel to calculate the no. of rotations of the wheel. Tachometer is used to measure the rotation of the wheel. The number of times the radium sticker passes/cuts through the tachometer is the no. of rotations the wheel is rotated.

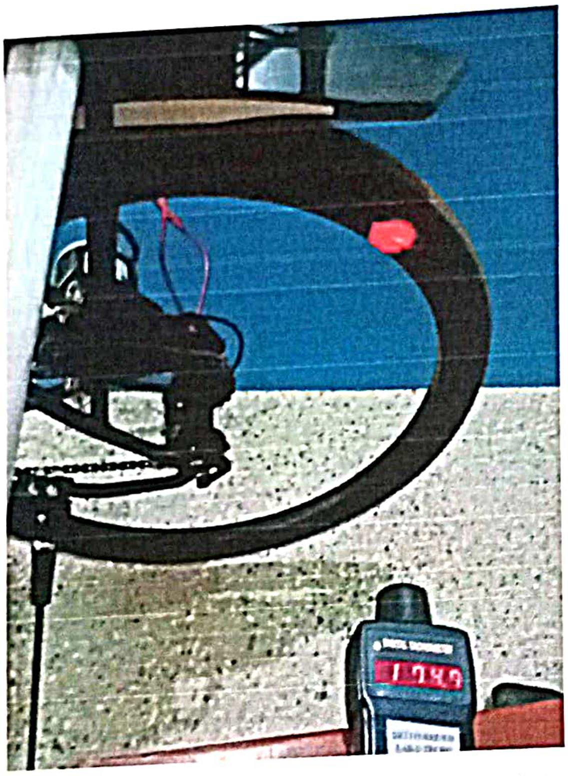

Fig 5.4: Tachometer measuring the rotation of the wheel

3. Throttle is twisted/turned allowing the motor to rotate and the amount of current drawn for a particular voltage is noted down along with the wheel rotation in RPM. The values are noted until the maximum voltage is reached.
4. The same procedure is followed for Lithium-ion battery as well.

5.1 SMF Battery Readings

The formula to calculate speed of the bicycle is given as

$$s=d*r*0.001885 \qquad (5.1)$$

Where, s = speed in Km/hr

d = wheel diameter in cm

r = rotation of wheel in RPM

Table 5.1: First Trial Readings

V_{input}, Volts	V_{load}, Volts	I, Amps	Power, Watts	RPM	Speed, Kmph
3.8	3.6	0.9	3.24	51	6.20
4.6	4.5	0.95	4.27	62	7.59
5.4	5.3	1.02	5.40	74	9.06
6.1	6.1	1.05	6.40	86	10.53
7.4	7.3	1.06	7.73	106	12.98
9.0	8.9	1.12	9.96	132	16.17
10	9.9	1.15	11.38	146	17.88
11	11	1.17	12.87	163	19.97
12.1	12.1	1.19	14.39	181	22.17
13.1	13.3	1.24	16.49	200	24.50
14	13.9	1.26	17.51	211	25.85
14.3	14.3	1.26	18.01	215	26.34
15.1	15.1	1.27	19.17	228	27.93
16.1	16.0	1.30	20.8	243	29.77
17.0	17.0	1.32	22.44	260	31.85
18.0	17.9	1.32	23.62	275	33.69
19.0	18.9	1.56	29.48	292	35.77
20.2	20.1	1.34	26.93	313	38.35
21.2	21.1	1.34	28.27	330	40.43
22.3	22.1	1.30	28.73	344	42.14
23.1	23.0	1.29	29.67	363	44.47
24.5	24.3	1.3	31.59	382	46.80
26.1	26.0	1.3	33.8	414	50.72
27.2	27.1	1.35	36.58	433	53.05
28	27.9	1.29	35.99	466	57.09
29	28.9	1.3	37.57	483	59.17
30	29.8	1.27	37.84	495	60.64

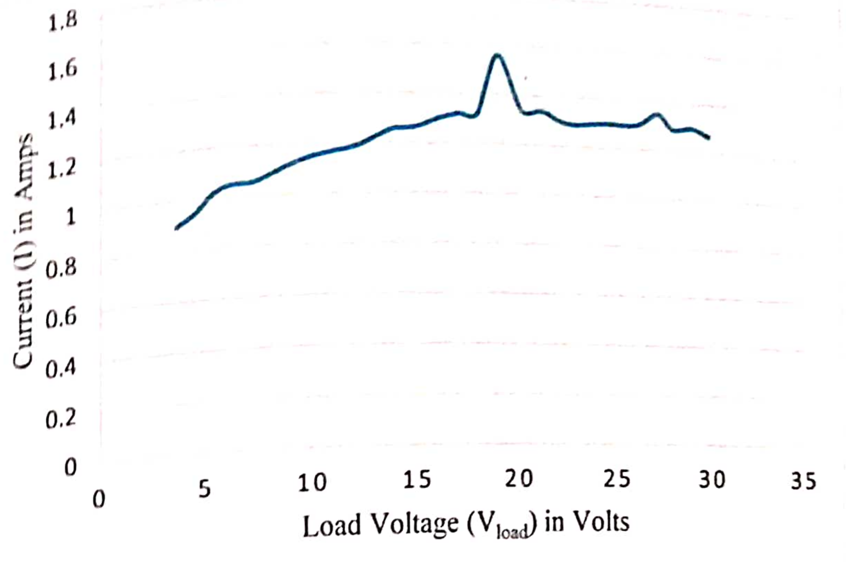

Fig 5.5 (a): Load Voltage v/s Current for SMF battery (1st trial readings)

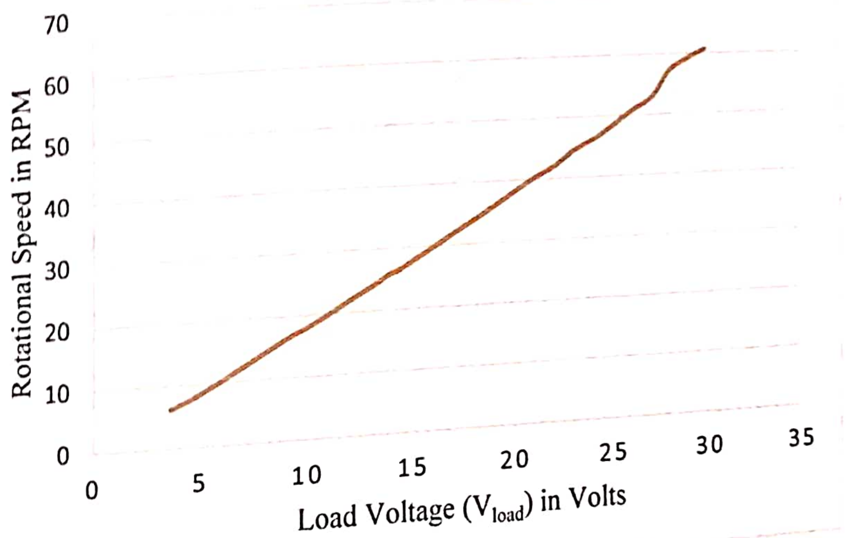

Fig 5.5 (b): Load Voltage v/s Rotational speed for SMF battery (1st trial readings)

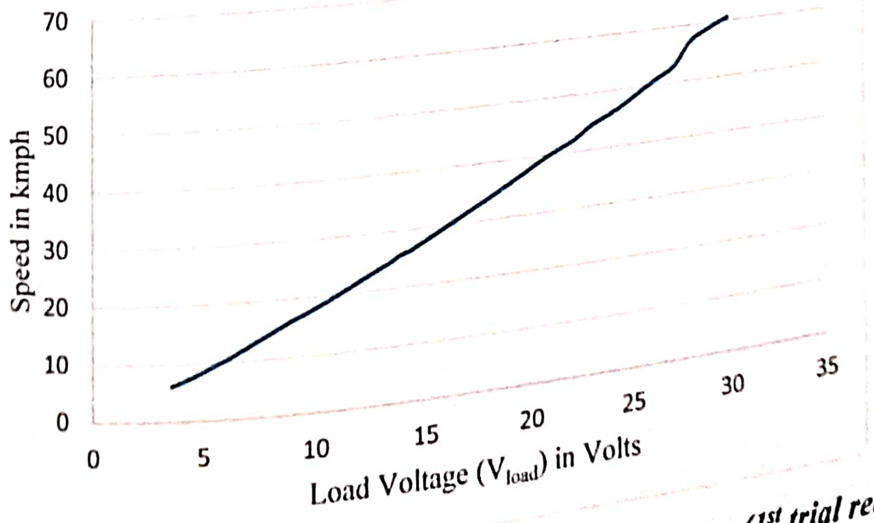

Fig 5.5 (c): Load Voltage v/s Speed of bicycle for SMF battery (1st trial readings)

Table 5.2: Second trial readings

V_{input}, Volts	V_{load}, Volts	I, Amps	Power, Watts	RPM	Speed
2.1	2.1	0.69	1.449	25	3.06
3.2	3	0.78	2.34	40	4.90
5.0	4.9	0.9	4.41	69	8.45
7.3	7.2	1.04	7.48	102	12.49
9.2	9	1.09	9.81	133	16.29
11.0	10.8	1.11	11.98	162	19.84
13.0	12.9	1.15	14.83	194	23.76
15.2	15.1	1.24	18.72	230	28.18
17.1	17.0	1.26	21.42	263	32.22
19.2	19	1.27	24.13	297	36.38
21.4	21.2	1.27	26.92	333	40.80
23.1	23	1.27	29.21	362	44.35
25.1	25	1.27	31.75	396	48.51
27.2	27	1.26	34.02	431	52.80
29.2	29	1.25	36.25	465	56.97
30	29.8	1.25	37.25	480	58.81

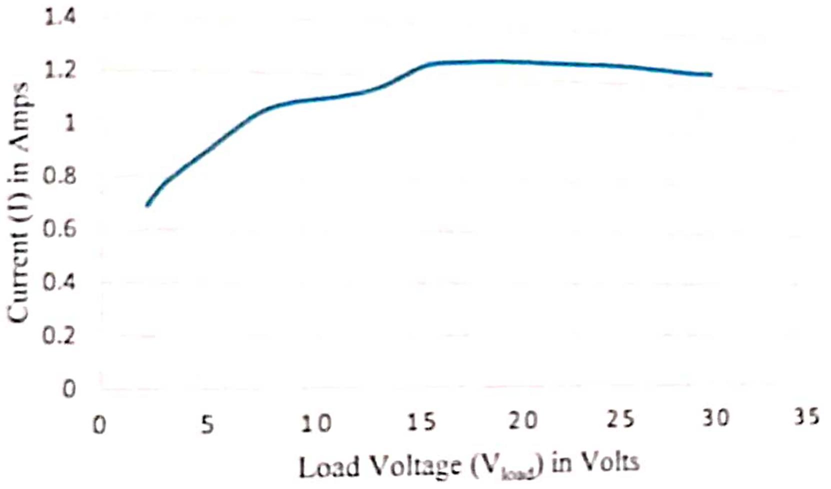

Fig 5.6 (a): Load Voltage v/s Current for SMF battery (2nd trial readings)

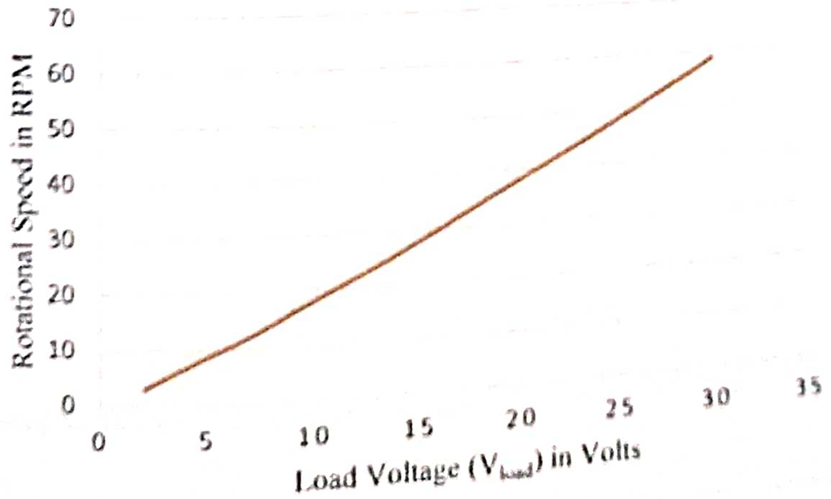

Fig 5.6 (b): Load Voltage v/s Rotational speed for SMF battery (2nd trial readings)

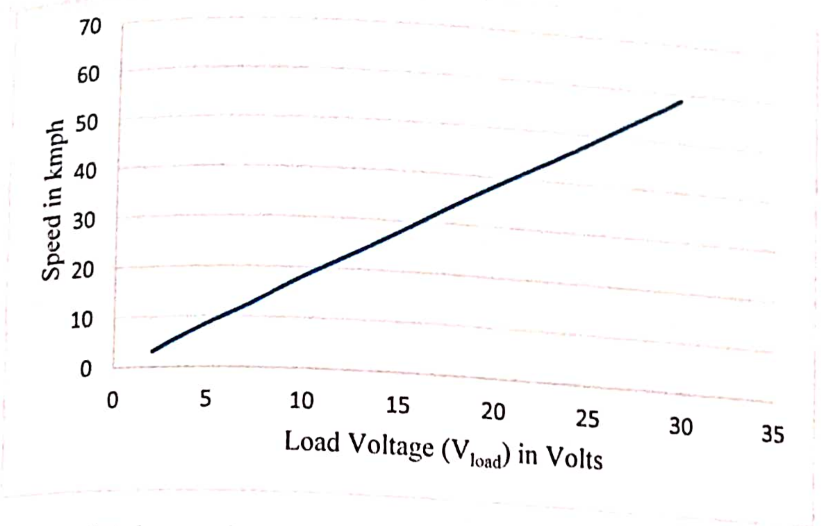

Fig 5.6 (c): Load Voltage v/s Speed of bicycle for SMF battery (2nd trial readings)

Table 5.3: Two batteries connected in parallel combination

V_L	I	$P=V_L*I$
4.05	0	0
3.19	1.3	4.14
2.55	2.23	5.94
2.15	2.81	6.04
1.98	3.03	5.99
1.91	3.05	5.82
2	3.02	6.04

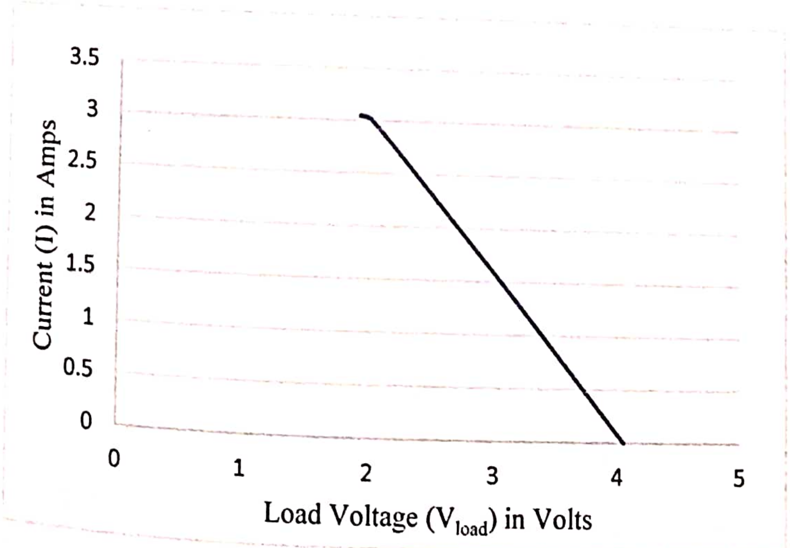

Fig 5.7: Load voltage v/s Current for parallel combination of SMF batteries

5.2 Lithium-Ion Battery Readings

Table 5.4: First trial readings

V_{open}, Volts	V_{load}, Volts	I, Amps	Power, Watts	RPM	Speed, Kmph
3.1	3	0.2	0.6	23.6	2.89
6.2	6	0.4	2.4	49.6	6.07
9.1	9	0.57	5.13	74.4	9.11
12.1	12	0.8	9.6	103	12.62
15.2	15	1	15	128.9	15.79
18.1	18	1.12	20.16	156.7	19.19
21.2	21	1.35	28.35	183.1	22.43
24.1	24	1.49	35.76	210.2	25.75
27	26.8	1.58	42.344	232.6	28.49

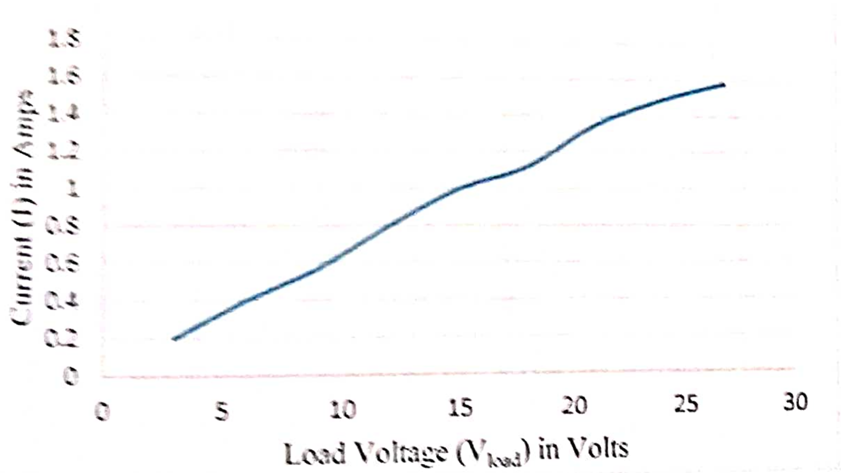

Fig 5.8 (a): Load Voltage v/s Current for Li-ion battery (1^{st} trial readings)

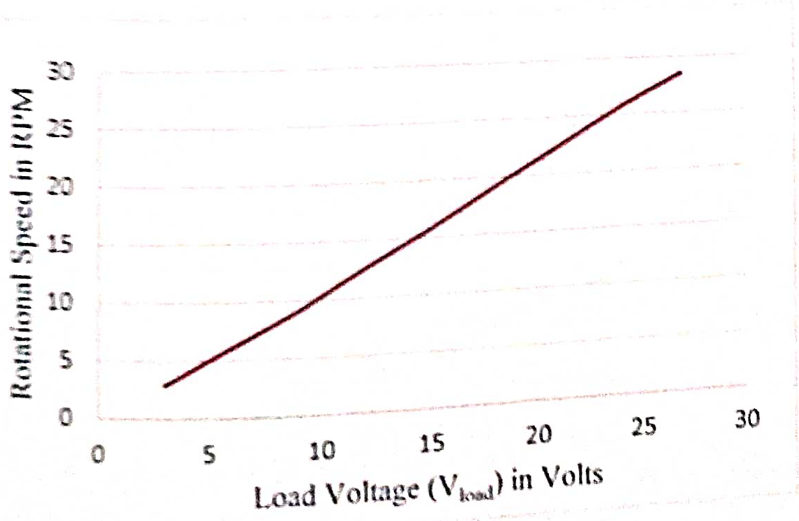

Fig 5.8 (b): Load Voltage v/s Rotational speed for Li-ion battery (1^{st} trial readings)

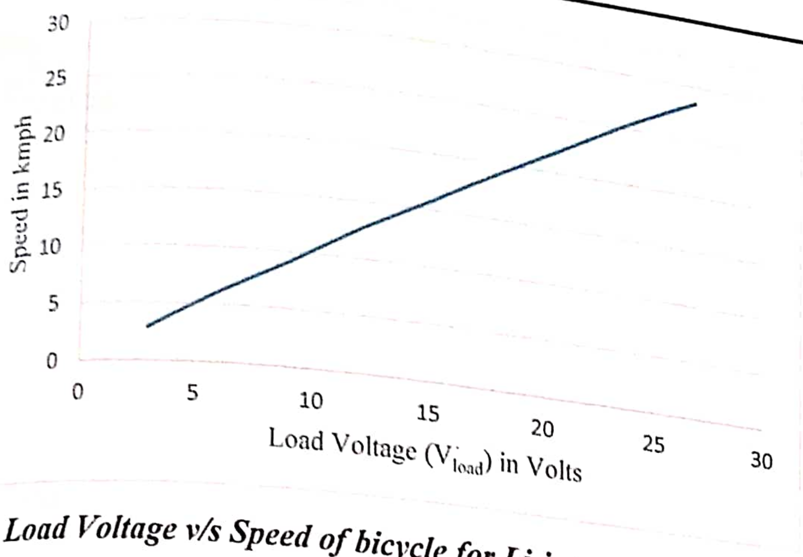

Fig 5.8 (c): Load Voltage v/s Speed of bicycle for Li-ion battery (1st trial readings)

Second trial readings

V_{input}, Volts	V_{load}, Volts	I, Amps	Power, Watts	RPM	Speed
2.2	2	0.12	0.24	21.8	2.67
4.1	4	0.21	0.84	32.6	3.99
6.3	6	0.34	2.04	46.5	5.69
8.2	8	0.46	3.68	66.6	8.16
10.3	10	0.56	5.6	86.5	10.59
12.1	12	0.66	7.92	101.2	12.39
14.3	14	0.73	10.22	120.7	14.78
1.2	16	0.85	13.6	137.6	16.85
18.2	18	1.03	18.54	154.2	18.89
20.3	20	1.17	23.4	173.9	21.30
22.1	22	1.23	27.06	188	23.03
24.2	24	1.43	34.32	211.2	25.87
26.2	26	1.66	43.16	228.7	28.02
27.4	27.2	1.94	52.768	237.2	29.06

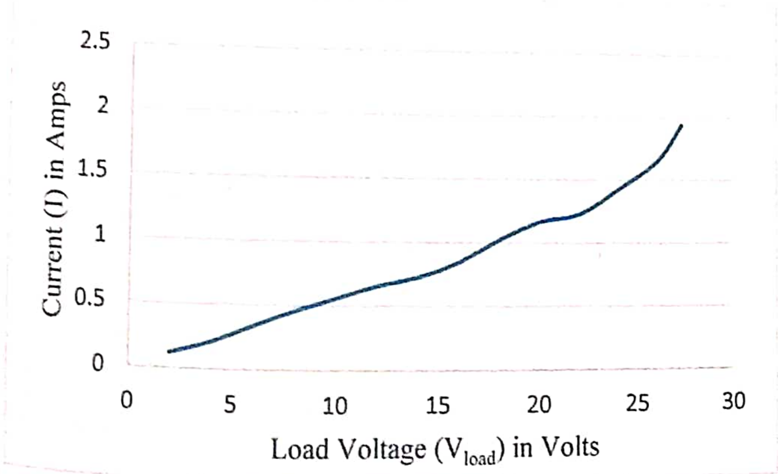

Fig 5.9 (a): Load Voltage v/s Current for Li-ion battery (2nd trial readings)

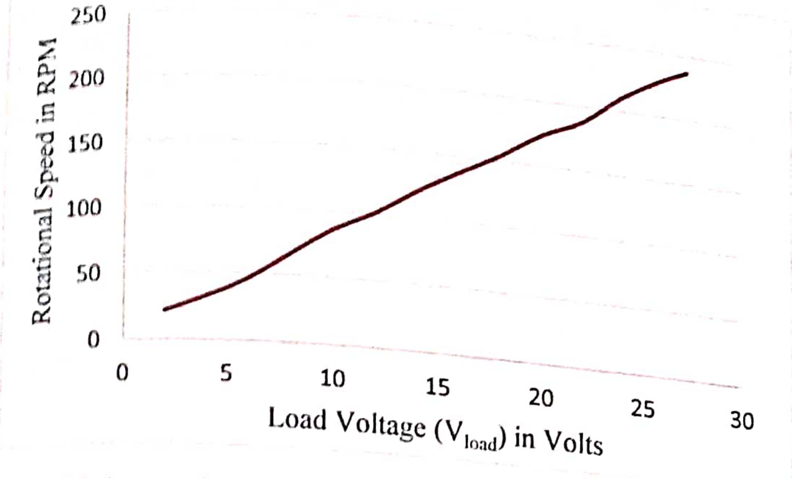

Fig 5.9 (b): Load Voltage v/s Rotational speed for Li-ion battery (2nd trial readings)

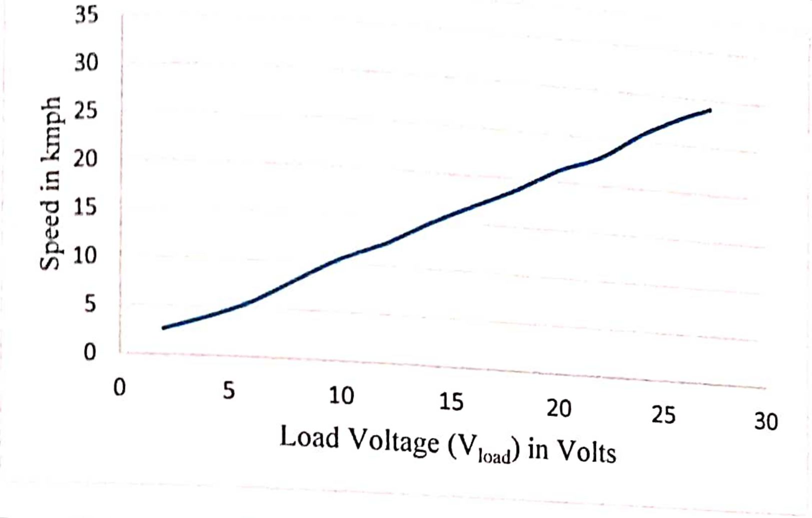

Fig 5.9 (c): Load Voltage v/s Speed of bicycle for Li-ion battery (2nd trial readings)

Comparison Of Batteries

results of SMF battery and Lithium-ion battery are compared with each other respectively.

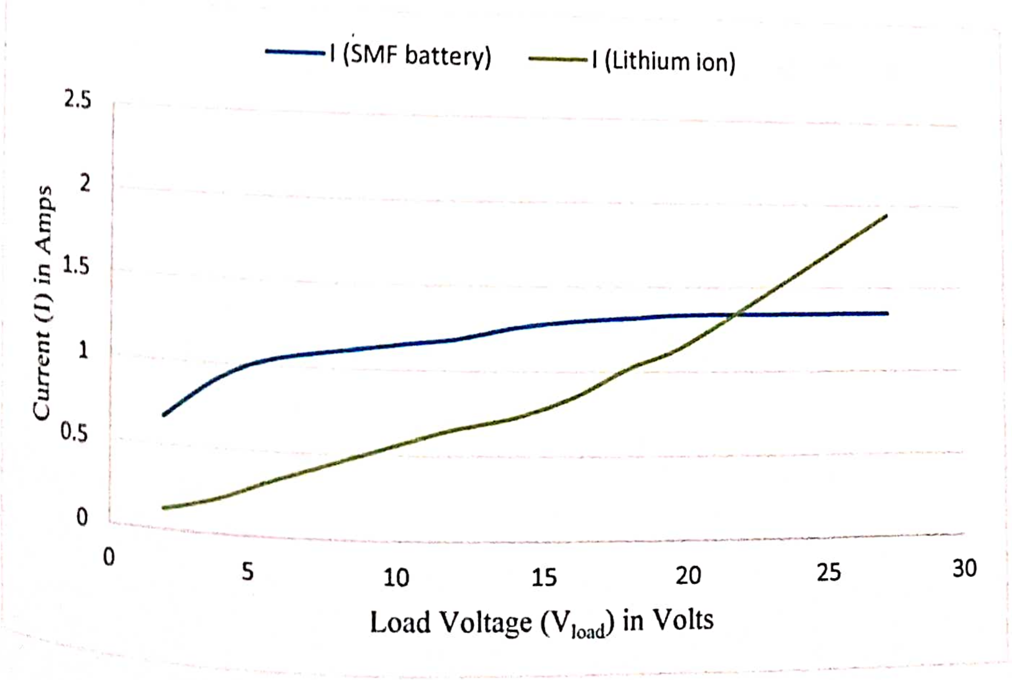

Fig 5.10 (a): Comparison of Load voltage v/s Current

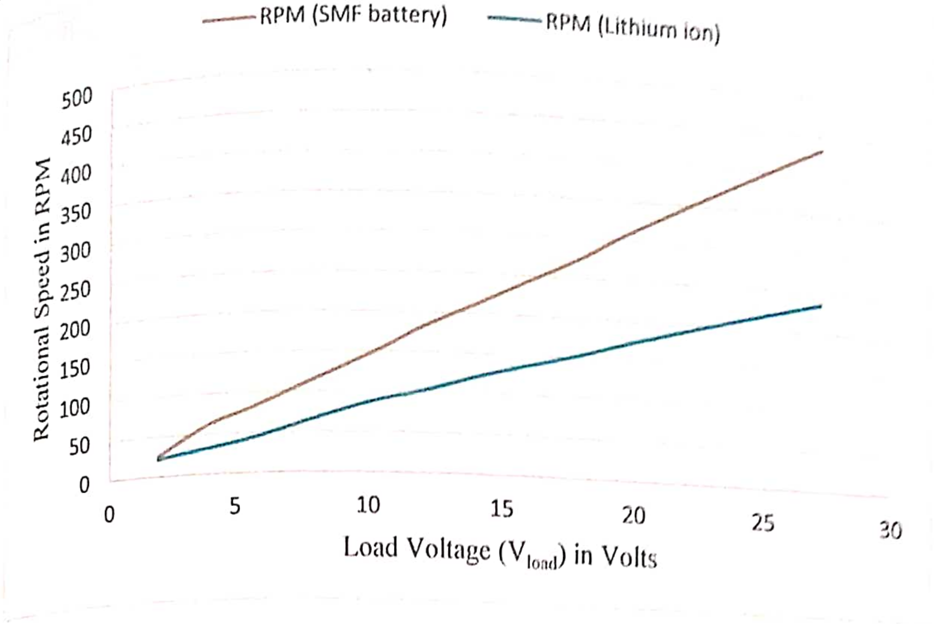

Fig 5.10 (b): Comparison of Load voltage v/s Rotational speed

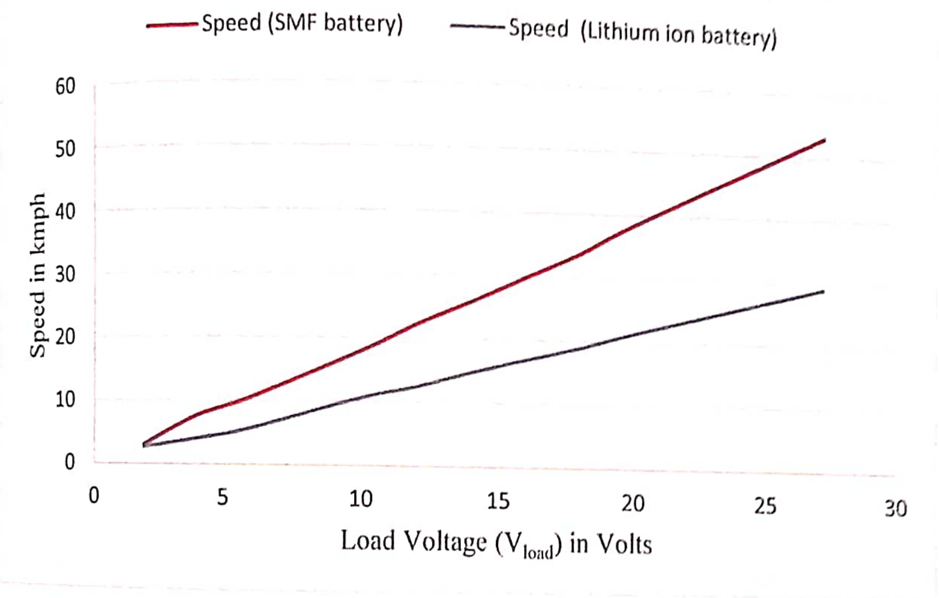

Fig 5.10 (c): Comparison of Load Voltage v/s Speed of bicycle

Chapter 6

CONCLUSION

During these semesters the electric bicycle project has provided an opportunity to grasp the full scope of what it means to Design a product. This opportunity allowed an initial idea/goal to be realized in a team environment. The idea developed as research and various other information on the topic was obtained. The goals were divided among the team members. In order to meet the deadline for the final project, progress was monitored weekly and individual goals were readjusted as needed. With communication between the team, and hard work, the final objective was obtained. The design project provided the team with valuable experience in design and teamwork. It allowed the team members to develop skills that will be useful in future endeavours. It is clearly seen that now a day the electrical bicycle gives a clean and more economical solution to the energy crises. In this project we have successfully developed, analysed and brought a comparison between two batteries (i.e. lithium ion battery and SMF battery) and we have plotted the performance characteristics of the electric bicycle by giving the proper inputs and mounting the advanced equipment sand by using the Two batteries successfully driven the bicycle.

In project phase 1 literature survey on Design of electric powered bicycle has been made. Methodology has been identified and it is proposed to fabricate an electric powered bicycle during phase 2.

6.1 Benefits of Using Electric Bicycle

1) ***Assisted biking:*** E-bikes have what they call battery-powered “pedal assist.” Technically, this is a machine integrated within the bike to give your pedalling a boost. This can reduce stress and impact on your knees and thighs [34]. Say goodbye to sweaty rides. There are E-bikes that have specific boosting technology that can assist you to conquer hills and inclines, so you don't have to worry about any challenging terrain. People of all ages and health can ride flawlessly and for much longer with an E-bike.
2) ***Fast and flexible:*** The technology gives you the extra oomph you need to cover miles of distance with little effort. You can also still take advantage of the multi-purpose cycle lane and paths that are traffic free, brilliant if you’re living in a city to slash your commute time. These are getting more and more popular in cities as governments and councils urge people to give up their car.

The bikes have been developed over the years and now look almost like a normal bike frame, with only the subtle 'hum' giving them away. Take advantage of the lithe form and durability of an E-bike without anyone being the wiser

3) *Improve fitness:* According to a study of scientists at Switzerland's University of Basel, riding an E-bike is just as good as regular bikes at improving fitness. Although cycling with an E-bike is pedal assisted, it's still an exercise after all and therefore good for your health, both mentally and physically. If you are more into fitness, there are customizable ones suitable for exercise, try looking at and comparing these before purchasing.

4) *Cuts-off expenses:* If you use the E-bike instead of a motor vehicle it will save you money in the long run. Petrol and diesel are costly in most countries, and occasional price surges can really impact on your budget. While with E-bikes, you can buy affordable batteries which can last you 18-50 miles after a full charge depending on the level of assistance you use.

) *They're the future of transportation:* We have all seen it in sci-fi movies. Sleek and sexy vehicles, none of which look old, bulky or have jets of smoke coming out the back, un-futuristic transportation is no longer being made. The electric bike is on its way to being up there with its smart counterparts. Considering that this invention will improve continuously over time, what we have now might be the prototype of this promising transport. Many countries in Southeast Asia took the lead in using E-bikes as sustainable mode of transportation, and with the continuous rise of urban air pollution, there is a big future for E-bikes.

) *Nature-friendly:* Climate change and global warming are serious issues and we all need to play our part. We might be facing our last stand to save our dying earth, and we can all contribute to this. E-bikes emit lower pollution per kilo meter than motorcycles and cars. You can help by using an E-bike instead of a petrol or diesel car. They use energy with an average rate of 100 to 150 watts compared to 15,000 or so for a car. As a result, this can help to improve air quality.

7) *Wide variety of designs:* With technology, everything is almost possible, and as the marketability of bikes increases, companies produce a variety of designs that can accommodate your needs. If there isn't the perfect one out there right now, you can be pretty sure there will be soon.

6.2 Disadvantages of Electric Bicycle

1) ***Significant upfront investment:*** It's not uncommon for people learning about electric bikes for the first time to be surprised by the cost of an e-bike, which typically ranges anywhere from $1,000 to $10,000. And while there's no getting around the fact that using an e-bike requires a significant upfront investment, the good news is that once you've spent the money to purchase a high quality electric bike, there are relatively few expenses required to operate it. Similarly, the cost of purchasing an electric bike is actually not too bad when compared to what it costs to buy a car or even a high-end bicycle.
2) ***Heavier than conventional bikes:*** Even after dramatic improvements in e-bike technologies and components, electric bikes remain noticeably heavier than conventional bicycles [34]. This becomes a problem primarily when you're trying to transport the bike or when you're out on a ride and the battery dies.
3) ***Charging time and range:*** To make sure that the pedal assistance does not unintentionally stop, the battery of the e-bike needs to be charged regularly. Basically, this is not a particularly difficult task, but you need to remember doing it early enough. Once empty, the battery takes at least one up to four hours to fully recharge again. Therefore, always keep an eye on the range of your e-bike. However, depending on the kind of battery, the range goes up to over 140 km, so usually, this should not be a real problem.

6.3 Future Scope

- With some of India's biggest automobile makers getting involved into electric vehicles segments, E-bikes, Scooters & bikes are going mainstream. Indigenous start-ups like Anther energy, Torque motorcycles, Emflux, Ultra Violette automotives, Orxa energies and Yulu adding to influx, backed by the government 'Make in India' initiative.
- Government of India has fixed a target of taking electric vehicles production up to 30% of two wheelers and cars by 2030, from the current stand of less than 1% . The sector holds immense scope since middle and lower income groups are often hit by the hike in fuel prices and hence are most likely to make the 'Big Switch' from petrol & diesel-run automobiles to EV's.

REFERENCES

[1] Vivek V Kumar, Karthik A, Ajmal Roshan, Akhil J Kumar, **"Design and Implementation of Electric AssistedBicycle with Self Recharging Mechanism"**, proceedings of International Conference On Innovations & Advances In Science, Engineering AndTechnology [IC - IASET 2014].

[2] C. Abagnalea, M. Cardoneb, P. Iodicea, R. Marialtoc, S. Stranoa, M. Terzoa, G. Vorraro, **"Design and Development of an Innovative E-Bike"**, proceedings of 71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16September 2016, Turin, Italy.

[3] History of electric bicycles (En.wikipedia.org/wiki/Electric_bicycle)

[4]Advantages of electric by cycles (lightspeed.bike>top-10-benefits- of -electric-bicycles)

[5] Vladimir Dimitrov, **"Overview of the Ways to Design an Electric Bicycle"**, Proc. IX National Conference with International Participation "Electronica 2018", May 17 - 18, 2018, Sofia, Bulgaria.

[6] Chyi-Ren Dow, Shun-Ming Chang, Van-Tung Bui and Pei Liu, **"A Vibration Reduction System for E-bikes"**, Department of Information Engineering and Computer Science Department of Transportation and Logistics, Feng Chia University, Taichung, Taiwan.

[7] Yassine Boukadida, Ahmed Masmoudi, Giovanni MercurioCasolino and Fabrizio Marignetti, **"A Simple Assessment of the Dynamics of the Road Vehicles"**, 2018 Thirteenth International Conference on Ecological Vehicles and Renewable Energies (EVER).

[8] Zhu Deyi1, Zhang Kai1, Yin Dejun, **"A New Torque Control Approach for Electric Power Assisted Bicycle Based on Model-Following Control"**, Proceedings of the 2017 IEEE International Conference on Information, Communication and Engineering IEEE-ICICE 2017 - Lam, Meen& Prior (Eds).

[9] Florin Dumitrache, Marius Catalin Carp and Gheorghe Pana, **"E-bike electronic control unit"**, 2016 IEEE 22nd International Symposium for Design and Technology in Electronic Packaging (SIITME).

[10] Madhav D. Kolgaonkar, Suraj S. Khanvilkar, Makarand D. Adarkar, Amey S. Joshi, Nitin K. Rahate, Santosh D. Sawant, **"Arduino Based Hybrid Power Auto Cycle"**, Proceedings of the 2nd International conference on Electronics, Communication and Aerospace Technology (ICECA 2018).

[11] Chun-Feng Huang, Bang-Hao Dai, and T.-J. Yeh, “**Observer-Based Sensor Fusion for Power-Assist Electric Bicycles**”, 2016 American Control Conference (ACC), Boston Marriott Copley Place, July 6-8, 2016. Boston, MA, USA.

[12] Zhang Kai, Yin Dejun, “**A Control Approach Adaptive to Load and Road Slope for Electric Power Assisted Bicycle**”, Proceedings of the 36th Chinese Control Conference, July 26-28, 2017, Dalian, China.

[13] Nikhil Hatwar, Anurag Bisen, HarenDodke, AkshayJunghare, “**Design Approach for Electric Bikes Using Battery and Super Capacitor For Performance Improvement**”, Proceedings of the 16th International IEEE Annual Conference on Intelligent Transportation Systems (ITSC 2013), The Hague, The Netherlands, October 6-9, 2013.

[14] Józef Gromba, “***Torque Control of BLDC Motor for Electric Bicycle***”, Department of Power Electronics and Energy Control Systems, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY Cracow, Poland.

[15] Ramchandra Nittala, G. Sridhar Babu, V. Sumadeepthi, “**Power E- Bicycle**” in page no. proceedings of International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 6 Issue V, May 2018.

[16] Brandon hayes, Louis Goguely, “**Bicycle power generation design for DC house**”, California polytechnic state university, San Luis Obispo.

[17] Divya P, Gosh U, Amrita, “**E-CYCLE an offgrid solution for rural electrification**”, center for wireless network & application, Amrita school of engineering Kerala India.

[18] N. Pavan Kumar Reddy, K.V.S.SVishnu Prasanth, “**Next Generation Electric Bike**”, proceedings of IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI-2017).

[19] Srivatsa Raghunath, “**Hardware Design Considerations for an Electric Bicycle Using a BLDC Motor**”, proceedings of Application Report SLVA642A–June 2014.

20] Chun-Lin, Chen, Chun-Chin Wang, Mi-Ching Tsai, and Po-Jen Ko, “**Control System Design f Power Assisted Bike Based on Planetary Gear**”, proceedings of First International ymposium on Instrumentation, Control, Artificial Intelligence, and Robotics (ICA-SYMP)-2019.

21] Y. Kuang, T. Ruan, Z. J. Chew, and M. Zhu, “**Energy harvesting during human walking to ower a wireless sensor node,**” Sensors and Actuators A: Physical, vol. 254, pp. 69 – 77, 2017.

[22] A. Doig, **"Off-grid electricity for developing countries,"** IEE Review, vol. 45, no. 1, pp. 25–28, Jan 1999.

[23] R. Ramakumar, **"Energizing rural areas of developing countries usingires"**, in IECEC 96. Proceedings of the 31st Intersociety Energy Conversion Engineering Conference, vol. 3, Aug 1996, pp. 1536–1541 vol.3.

[24] T. D. Heeten, N. Narayan, J. C. Diehl, J. Verschelling, S. Silvester, J. Popovic-Gerber, P. Bauer, and M. Zeeman, **"Understanding the present and the future electricity needs: Consequences for design of future solar home systems for off-grid rural electrification,"** in 2017 International Conference on the Domestic Use of Energy (DUE), April 2017, pp. 8–15.

25] Ian Vince McLoughlin, I. Komang Narendra, Leong Hai Koh, Quang Huy Nguyen, Bharath Seshadri, Wei Zeng, Chang Yao, **"Campus Mobility for the Future: The Electric Bicycle"**, roceedings of Journal of Transportation Technologies, 2012, 2, 1-12.

26] https://www.engineersgarage.com/contributions/sealed-maintenance-free-smf-batteries/

27] Da Deng, **"Li-ion batteries: basics, progress, and challenges"**, published in 2015 Energy cience & Engineering published by the Society of Chemical Industry and John Wiley & Sons td.

28]http://www.altenergymag.com/content.php?post_type=1884#_edn2

29] https://www.electrical4u.com/permanent-magnet-dc-motor-or-pmdc-motor/

30] https://electricbikereport.com/electric-bike-throttle-pedal-assist-pedelec/

31] https://www.bikeradar.com/features/e-bike-power-throttle-vs-pedal-assist/

32]https://avt.inl.gov/sites/default/files/pdf/fsev/power.pdf#:~:text=The%20electric%20vehicle%
0controller%20is%20the%20electronics%20package,like%20a%20carburetor%20does%20in%2
a%20gasoline-powered%20vehicle

3] http://mechdiploma.com/explain-working-freewheel-mechanism-bicycle-sketch

4] https://www.evelo.com/buyers-guide-source/09-pros-cons-electric-bikes.html

5] https://www.elecycles.com/blog/post/what-you-need-to-know-about-electric-bike-controller/