International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 10 Issue 6 ǁ 2022 ǁ PP. 1677-1684

Electric Bicycle

Bibin Thomas A*[1], Jis N George[1],Joyal George[1], Rohan Abraham John[1]
[1]*Mar Athanasius College of Engineering , Kothamangalam ,Kerala, India*

Abstract
Electric bicycles offer power assistance to the rider through a motor compared to normal bicycles. Energy required to run the motor is generally stored in a battery. The assistance of electric motor is very helpful especially when riding uphill as higher torque is required for riding bicycle uphill. It will significantly reduce the exhaustion of the rider. The rider has also the option to pedal with or without the assistance of the motor or to run bicycle without pedalling using motor. This makes electric bicycles versatile. Our project aims to develop an electric bicycle and enhance the ride quality of electric bicycles and to extend its riding range by capturing the kinetic energy from the wheel and storing it to battery. The features that enhance ride quality are pedal assist, cruise control and reverse motoring. The features that aim to extend riding range are regenerative braking and power generation mode. Pedal assist adjust the power assistance to the rider according to the effort of the rider. Cruise control helps to maintain bicycle speed above a certain set speed and the motor assists to attain that speed according to the pedalling speed of the rider. Reverse motoring moves the bicycle in reverse direction, which is very helpful when the bicycle needs to be pulled backwards in a downhill. Regenerative braking captures the converts the kinetic energy of the wheel to electrical energy and stores it in battery when brakes are applied, thus recovering energy and producing a braking effect. Power generation mode is similar to regenerative braking except that it captures energy from the wheel whenever the wheel moves.
Keywords: *Hall-Effect sensors, BMS,$LiFePO_4$,Cruise control,Pedal assist.*

Date of Submission: 12-06-2022 Date of acceptance: 26-06-2022

I. INTRODUCTION

Electric bicycles improve the power and comfort of bicycles. It is also an environmentally friendly mode of transportation that can use both manpower and motor power according to the convenience of the rider. This makes electric bicycles more dependable and reliable for daily use. The cost of an electric bicycle is generally lower than that of an electric motorbike or and electric scooter. The design of electric bicycle varies according to its use, type of motor used and the position where motor is placed to provide power. Generally, electric bicycle motors are classified as hub motors and mid-drive motors. Hub motors offer the scope to implement regenerative braking compared to mid-drive motor. Our design uses a BLDC hub motor to power the bicycle. The speed of the bicycle is adjusted using throttle and brakes.tor to power the bicycle. The speed of the bicycle is adjusted using throttle and brakes. Higher energy density and comparable cost with similar batteries makes $LiFePO_4$ more popular in electric vehicles. We use $LiFePO_4$ batteries to power the motor. As every motor can also act as a generator, the generator action of BLDC motor is utilised for implementing regenerative braking and power generation mode. The data from Hall effect sensors of the motor and speed control of motor through variation of DC voltage on the throttle terminal of the motor controller is used to implement pedal assist, cruise control and reverse motoring. Various modes of operation and overall control of electric bicycle is implemented using Arduino Mega 2560 micro controller board.

Matteo Corno et al.[1]presented the design, control, and validation of a charge-sustaining parallel hybrid bicycle.

Nuzhat Nawshin et al.[2] concentrated on the Design and Development of BLDC controller and its implementation on E-Bike.

NitipongSomchaiwonget al.[3] describe a study and designed regenerative power control for an electric bicycle.

II. BLDC MOTOR AND CONTROLLER

The motor used for powering electric bicycle is a Brushless DC (BLDC) motor fitted to the rear wheel hub. It has three phases for exciting the windings and three Hall-effect sensors to detect the position of the rotor. It has a rated voltage of 36V and a rated power of 250W. It has an internal planetary gear system and a freewheel. We disabled the freewheeling mechanism to operate the motor as a generator as freewheel will stop the motor from rotation when the wheel speed is greater than motor speed. The motor will generate three phase AC voltage when operated as a generator. It can draw or supply current up to 7 A.

Figure 1: BLDC hub motor of the electric bicycle

The BLDC motor has a sinusoidal controller that excites the motor windings according to the data from the Hall-effect sensors. The controller has provisions for connecting throttle and brake signal cables and pedal assist sensors. It also has a safety feature for avoiding over discharge of battery bycutting the supply when battery voltage drops below 32 volts. The controller also cuts the supply to the motor whenever it receives a LOW input from the brake wires. The brake signals are active low.

III. SENSORS AND CONTROL

Hall effect sensors: These sensors work based on the Hall-effect. It is used to detect the position of rotor of the BLDC motor. The sensor data is communicated to the motor controller as HIGH or LOW voltages depending on the pole of the rotor which comes close to the sensor. When south pole of the motor comes close to the sensor, the sensor will give a HIGH output; when north pole of the rotor comes closer, sensor will give a LOW output. The HIGH voltage of Hall-effect sensors were in the range 4.5 to 5.05 volts. The LOW output was in the range 0 to 0.5 volts. Hall-effect sensors operate on a supply of 5 volts. It has 5 wires where two wires are supply and ground wires and other three are output wire of the three sensors.The BLDC motor has three Hall-effect sensors placed on the stator. They are placed 120◦ apart.

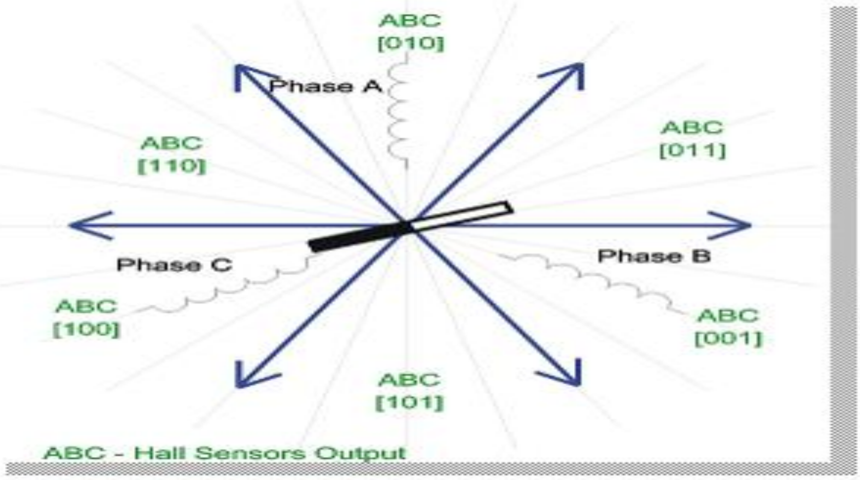


Figure 2Hall-effect sensor outputs on various rotor positions

Pedal assist sensor: Pedal Assist Sensor (PAS sensor) detects whether the pedals are moving or not. It can also be used to determine the speed of pedalling. PAS sensor has 8 magnets and a sensor to detect the proximity relative to the magnets. PAS sensor has three wires where one is the supply voltage wire, other is the ground wire and other is the output wire. PAS sensor operates on a supply of 5 volts. The sensor gives a 8 HIGH outputs with respect to the ground and 9 LOW outputs on one complete rotation of the pedal.

Brake sensors: Brake sensors are like a normal switch. When brake is not applied, the switch will open and voltage across the terminals will be HIGH. When brake is applied, switch is closed and voltage across the terminals will be LOW. So braking is detected from the LOW signal from the brake sensors.

Throttle and speed control: Throttle is used to control speed of the motor. Turning throttle increases the speed. Turning the throttle is converted to corresponding voltage variation and the motor controller changes the speed of the motor according to this voltage. When the throttle is not applied, it has 0.83 volts across it. When full throttle is applied, voltage goes up to 3.62 volts. Speed of the motor can be adjusted by applying voltage in this range across the throttle terminals of the motor controller externally, without turning the throttle.

IV. BATTERY

We have used 32700 model LFP cells which has 3.2 volts, 6000mah to design our battery. Each cell has a nominal voltage of 3.2 volts and full charge voltage of 3.65 volts. They have a continuous discharge current capability of 18 A and charge current capability of 6 A. They offer more than 2000 cycles life. We have used 22 cells arranged in 2P 11S fashion. Our requirement of 36 volts is satisfied with this arrangement. It can also provide very well more than 7 A of current. Cells were arranged using battery spacers and were joined by spot welding using nickel strips.Battery Management System is used as if different cells in a battery is charged to different levels, it will create imbalance in a battery pack and may reduce life of the battery. BMS equalises the charge of differentcells of the battery. It also gives over-discharge and over-charge protection. It also has the capability to detect temperature rise within the battery pack and cut the battery supply if necessary. BMS has connection to every cell of the battery pack.

All lithium-ion based batteries including LFP are charged by Constant Current - Constant Voltage method. The charging voltage of a single cell in the battery pack is 3.65 V. As 11 cells are arranged in series, a total charging voltage of 40.15 volts is necessary. Until voltage per cell reaches full chargevoltage of about 3.65 volts, it is charged in constant current mode and after that it is charged in constant voltage mode until the charge is full. The battery charging circuit of electric bicycle consists of a desktop computer SMPS which can supply 12 V DC voltage from AC mains supply and a 250 watt CC-CV boost converter which steps up battery charging voltage from SMPS to 40.15 volts and maintains constant voltage and constant current when required. The end of charge current of a single $LiFePO_4$ cell we used is 0.3 A.

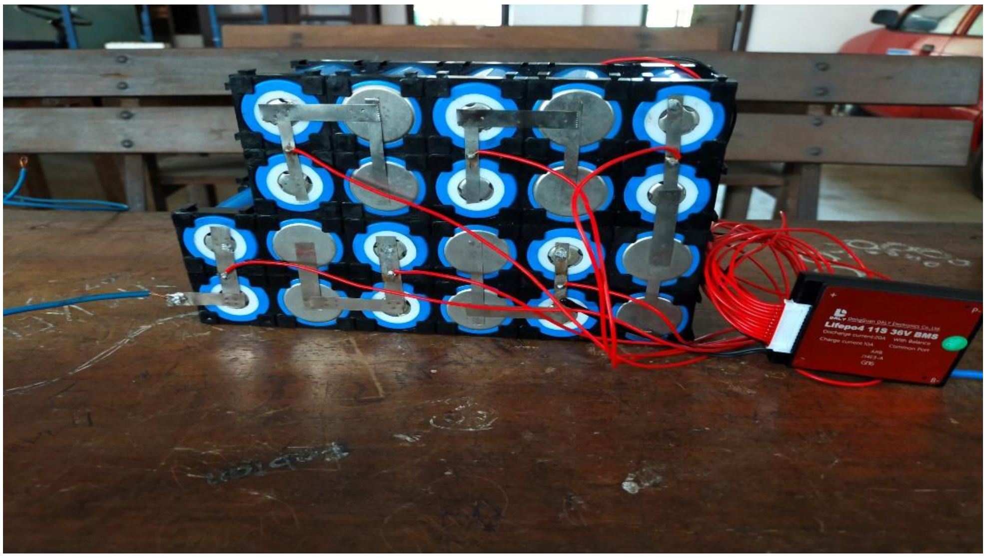


Figure 3Spot welded battery back with BMS

V. ARDUINO MEGA 2560AND LCD DISPLAY

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 microcontroller. It can be connected to the computer using a USB cable, can be powered using a battery or an AC to DC adapter supplying 7 to 12 volts. The analog pins can be used to read analog voltage up to 5 volts. The PWM pins can be used to produce variable voltage up to 5V using Pulse Width Modulation. The General Purpose Input Output (GPIO) pins of Arduino can source or sink maximum 40 mA current. Arduino Mega 2560 has six hardware interrupts.

LCD display JHD204A can display 4 lines of 20 characters each. It has 16 pins out of which 8 are data pins. It also has a LED back light. Characters can be displayed on the LCD using 4 data pins (4 bit mode) or 8 data pins (8 bit mode). Contrast and brightness of the display can be adjusted using external resistors. Arduino IDE has a library named LiquidCrystal for interfacing LCDs easily.

VI. SPEED ,DISTANCE MEASUREMENT, CRUISE CONTROL AND PEDAL ASSIST

To measure speed of the bicycle, the number of HIGH and LOW states of the square waves generated from a Hall-effect sensor was determined using CRO and Arduino. It was found that one complete rotation of bicycle wheel produces 90 HIGH and LOW states (taken together). For measuring speed, the number of HIGH-LOW states was detected using Arduino from a single Hall-effect sensor for one second.This was divided by 90 to get speed in rotations per second (rps) of the wheel. Multiplying rps speed with circumference of the bicycle wheel will give speed in meter per second of the bicycle. The flowchart of this program is shown in Fig.3. This can be converted to kilometer per hour and can be displayed on the LCD display or used for cruise control. Similarlyrps speed of pedal was determined using data from PAS sensor and was utilised for pedal assist. For PAS sensor 17 HIGH-LOW states were shown for one complete rotation of the pedal.

For measuring distance travelled by bicycle, the number of HIGH-LOW states of one Hall-effect sensor is measured and stored in a variable. It is divided by 90 (predetermined) to get the number ofrotations of the wheel. This result is multiplied by 2.07 (circumference of wheel in meters) to get the distance travelled by bicycle in meters. It is divided by 1000 to get the distance in kilometers. Distance shown in LCD is updated when distance increases by a kilometer. Distance is stored in the flash memory of Arduino Mega 2560 for recovering it when Arduino is turned ON after powering it OFF.

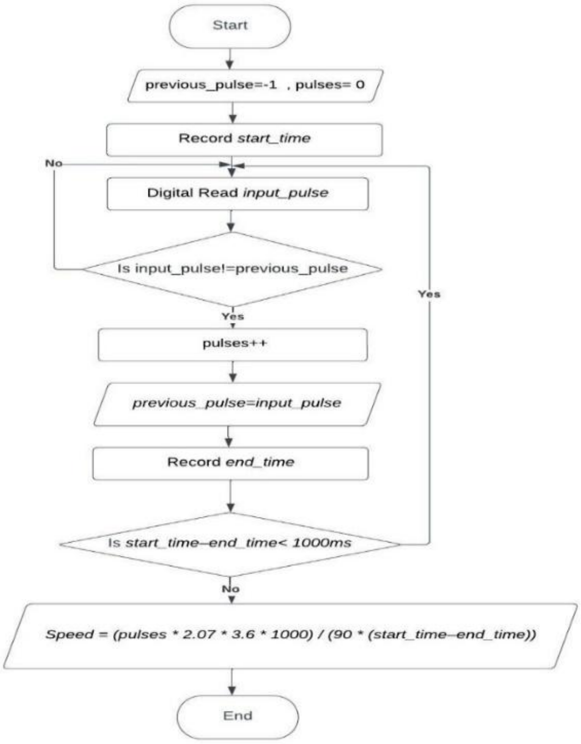
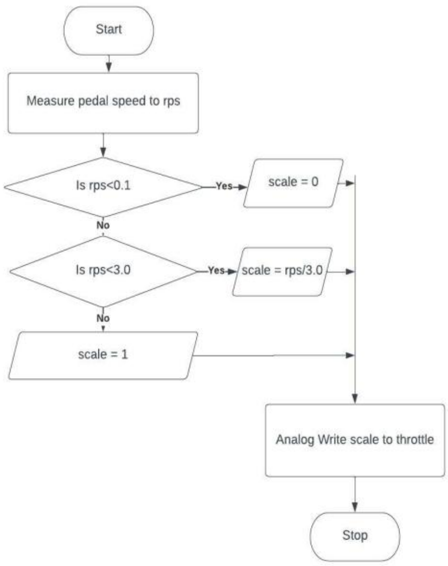


Figure 4 Flowchart of speed Measurement

A speed is chosen by the rider as cruise speed of the bicycle, using switches connected to Arduino. Speed of the pedals are continuously monitored from the data obtained from PAS sensor of the bicycle.



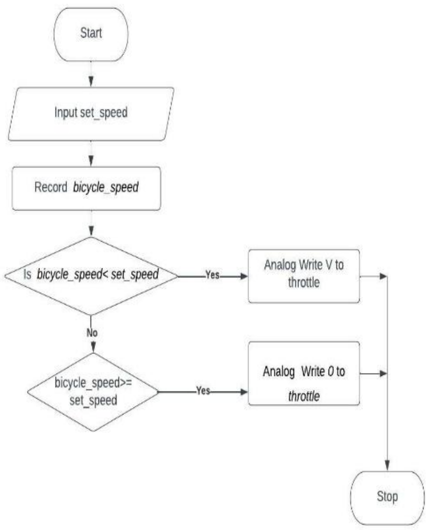


Figure 5 Flowchart of pedal assistFigure 6 Flowchart of cruise control

VII.REGENERATIVE BRAKING CIRCUIT

Regenerative braking circuit consists of three phase bridge rectifier and a smoothening capacitor constituting the DC power supply, a relay and a Constant Current - Constant Voltage (CC-CV) Boost converter. Three phase bridge rectifier converts three phase AC voltage to positive half cycles of sinusoidal voltage, which is made to DC voltage using a smoothening capacitor filter. This voltage is fed to CC-CV boost converter and is stepped up to 40.15 volts which is the required charging voltage. Relay is used to enable and disable regenerative braking and is placed in between DC power supply circuit and boost converter.10A10 R6 diodes are used for the three phase bridge rectifier circuit.Three 50V, 10000μF electrolytic capacitors are connected in parallel to get 30000μF capacitance for the reservoir capacitor.The CC-CV boost converter can step up variable DC voltage to a constant DC voltage.

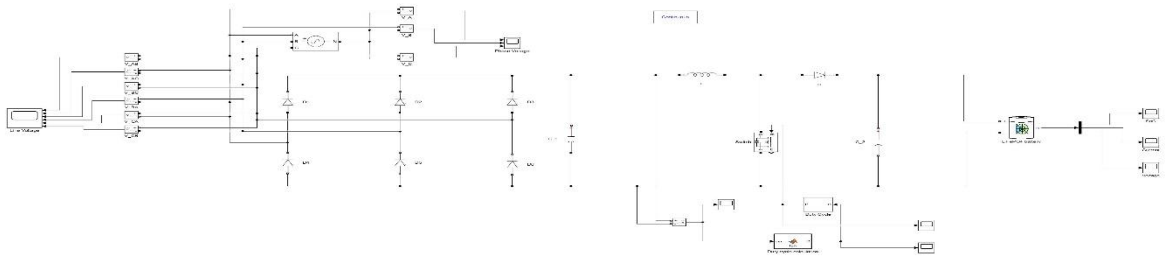
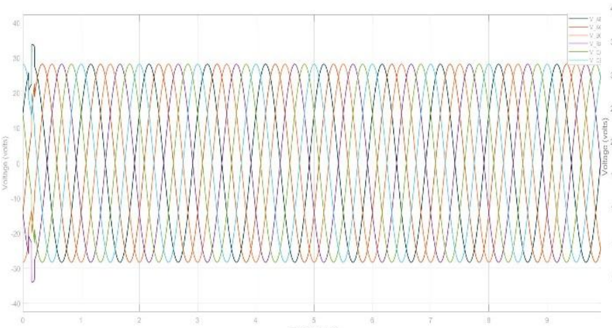


Figure 7Regenerative braking circuit for simulation.

VIII. SIMULATION

The circuit diagram is for MATLAB Simulink simulation is shown in Fig.7. Here instead of the BLDC motor acting as a generator and producing three phase voltage, a three phase voltage source is shown. Line to line voltages between the phases of the voltage source is shown in Fig.8 and Fig.10. The difference between both figures is that the show voltages of different magnitudes and frequency, which the BLDC motor generates when its speed of rotation is changed as bicycle wheel rotation speed is changed. Fig.9 and Fig.11 show the output of the regenerative circuit. Regardless of the change in magnitude and frequency of input voltages, the regenerative circuit produces a constant DC voltage to charge the battery. This is done by constantly varying the duty ratio of boost converter to produce constant voltage from varying DC voltages from the DC power supply part.



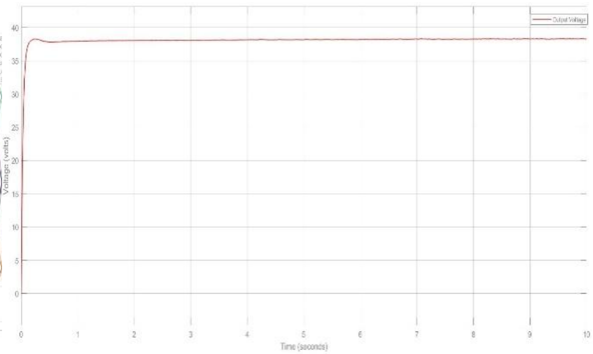
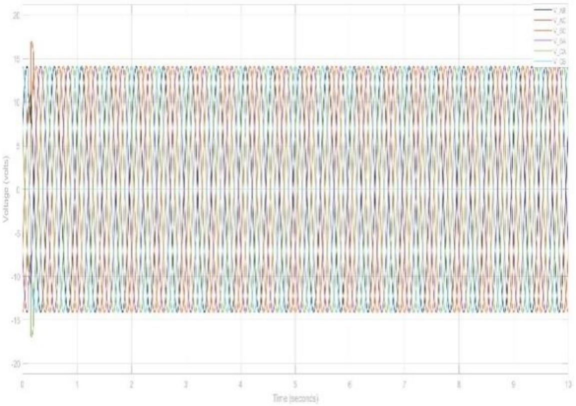


Figure 8 Line to Line voltage - 1 of BLDC Figure 9 Output voltage - 1 of regenerative circuit generator phases



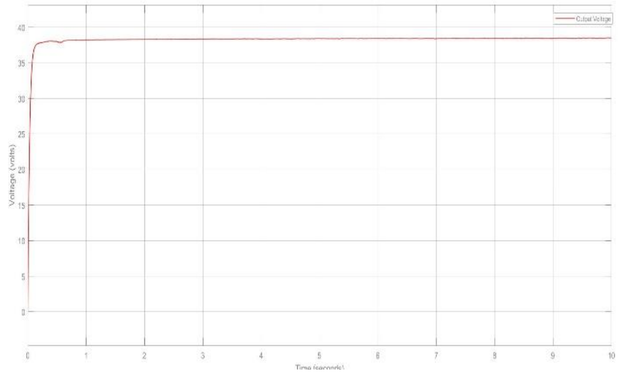


Figure 10 Line to Line voltage - 2 of BLDC Figure 11 Output voltage - 2 of regenerative circuit generator phases

IX. REVERSE MOTORING

For implementing reverse motoring, Hall-effect sensor data is given to Arduino. Arduino inverts the data by converting HIGH to LOW (1 to 0) and LOW to HIGH(0 to 1) and sends it to the controller. This inverted Hall-effect data will trigger the stator windings to be excited in such a fashion as to rotate the motor in reverse direction as evident from Fig.4.1 as stator windings as motor controller is already pre-programmed to excite stator windings as given in the figure 12.

Hall Sensor A	Hall Sensor B	Hall Sensor C	Phase A	Phase B	Phase C
1	0	0	-V	+V	NC
1	0	1	NC	+V	-V
0	0	1	+V	NC	-V
0	1	1	+V	-V	NC
0	1	0	NC	-V	+V
1	1	0	-V	NC	+V

Figure 12Hall-effect data and corresponding excitation

X. CONCLUSION

As the costs of new EVs are increasing, we start looking converting an existing bicycle into an electric bicycle. Electric bicycle is attracting significant attention worldwide due to its lightweight, compact design, and cheaper price than other electric vehicles. An electric bicycle has been successfully built using the following features like forward motoring, reverse motoring, regenerative braking,pedal assist and cruise control. Regenerative braking helps to recover some of the energy used back to the source thereby increasing fuel efficiency. Also power generation through pedalling is an alternate way to recharge the vehicle's battery. Bicycle battery can be charged from mains supply , using regenerative braking and power generation mode that increases the riding range of the bicycle and also increases the comfort of the rider. Speed of the bicycle , battery charge and battery voltage , mode of operation and distance travelled are displayed on LCD screen. When BLDC hub motor is used the bicycle becomes more compact and efficient. BLDC motors have reportedly hit 85% to 90% percent efficiency margin, which is higher than the standard brushed motors at 75% to 80% percent. Battery used is LiF ePO_4 which has excellent cycle life(more than 2000 cycles), excellent high and low temperature performance, steady voltage, low self-discharge. An electric bicycle is environment friendly, just like a normal bicycle. It does not produce harmful emissions into the atmosphere as it runs on electricity rather than fossil fuels. For the same reason, electric bicycles are as quiet and smooth as regular bicycles. BMS is required for the battery pack to maintain temperature and output level within ideal range hence improving the overall efficiency of the battery. Electrical assisted bicycles represent an emerging sustainable mode of transport for future smart cities. The implemenation power generation through normal pedalling and through regenerative braking increase the range of the bicycle considerably. Features like cruise control and reverse motoring improves the usability and comfort of the bicycle that suits the modern requirements.

REFERENCES

[1]. Matteo Corno et al.,"Design, Control, and Validation of a Charge-Sustaining Parallel Hybrid Bicycle", **IEEE Transactions On Control Systems Technology**

[2]. Nuzhat Nawshin et al., "Design and Development of BLDC Controller and its Implementation on E-Bike", **2018 International Conference on Recent Innovations in Electrical, Electronics Communication Engineering**

[3]. NitipongSomchaiwong et al.,"Regenerative Power Control for Electric Bicycle" **SICE-ICASE International Joint Conference**

[4]. E G Janardanan, "Special Electrical Machines", PHI Learning

[5]. Daniel W. Hart, "Power Electronics", Mc Graw Hill