# Design and Development of Hybrid Motor Bike by Using Hub Motor

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# Certification

This is to certify that **Muhammad Soban**, **19-ME-147, Muhammad Saad Ali, 19-ME-148** and **Muhammad Dawood**, **19-ME-166** have successfully completed the final project **Design and Development of Hybrid Motor Bike by Using Hub Motor,** at the **University of Engineering and Technology Taxila**, to fulfill the partial requirement of the degree **BSc. Mechanical Engineering.**

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# Design and Development of Hybrid Motor Bike by Using Hub Motor

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

| SDG No | Description of SDG | SDG No | Description of SDG |
|---|---|---|---|
| SDG 1 | No Poverty | SDG 9 ✓ | Industry, Innovation, and Infrastructure |
| SDG 2 | Zero Hunger | SDG 10 | Reduced Inequalities |
| SDG 3 | Good Health and Well Being | SDG 11 ✓ | Sustainable Cities and Communities |
| SDG 4 | Quality Education | SDG 12 | Responsible Consumption and Production |
| SDG 5 | Gender Equality | SDG 13 | Climate Change |
| SDG 6 | Clean Water and Sanitation | SDG 14 | Life Below Water |
| SDG 7 | Affordable and Clean Energy | SDG 15 | Life on Land |
| SDG 8 | Decent Work and Economic Growth | SDG 16 | Peace, Justice and Strong Institutions |
| | | SDG 17 | Partnerships for the Goals |


| **Range of Complex Problem Solving** | | | |
|---|---|---|---|
| | **Attribute** | **Complex Problem** | |
| 1 | Range of conflicting requirements | Involve wide-ranging or conflicting technical, engineering and other issues. | |
| 2 | Depth of analysis required | Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models. | |
| 3 | Depth of knowledge required | Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach. | |
| 4 | Familiarity of issues | Involve infrequently encountered issues | |
| 5 | Extent of applicable codes | Are outside problems encompassed by standards and codes of practice for professional engineering. | |
| 6 | Extent of stakeholder involvement and level of conflicting requirements | Involve diverse groups of stakeholders with widely varying needs. | |
| 7 | Consequences | Have significant consequences in a range of contexts. | |
| 8 | Interdependence | Are high level problems including many component parts or sub-problems | |
| **Range of Complex Problem Activities** | | | |
| | **Attribute** | **Complex Activities** | |

| | | | |
|---|---|---|---|
| 1 | Range of resources | Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies). | |
| 2 | Level of interaction | Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues. | |
| 3 | Innovation | Involve creative use of engineering principles and research-based knowledge in novel ways. | |
| 4 | Consequences to society and the environment | Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation. | |
| 5 | Familiarity | Can extend beyond previous experiences by applying principles-based approaches. | |

# Abstract

This project thesis presents the design and development of a hybrid motorbike utilizing a hub motor. The hub motor used in this project has a power rating of 900W and operates at 36V. The thesis focuses on the analysis of hub motor components, the functioning of the hall sensor, testing procedures, and challenges encountered during hub motor implementation. It also discusses the key design principles and criteria employed, including the integration of sensors and other technologies to enhance vehicle performance and efficiency. An important aspect of the project involves the utilization of alternative technology, specifically the use of battery electric energy to power the hub motor, reducing dependence on fossil fuels. To enable this, a microcontroller with embedded relays is implemented to facilitate seamless switching between two drive modes: petrol mode and electric mode. The motor controller efficiently manages power flow between the battery, electric motor, and engine to optimize performance. In conclusion, hybrid electric vehicles (HEVs) offer numerous advantages compared to conventional vehicles, making them an appealing choice for individuals seeking fuel efficiency and environmental friendliness. With ongoing technological advancements, the future prospects for HEVs are promising.

**Keywords:** Good driving stability, better driving performance, easy and intelligent control.

## Undertaking

WE certify that thesis titled "*Design and development of hybrid bike by using hub motor*" is our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred to.

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# Nomenclature

## Abbreviations

**BLDC:** Brushless Direct Current

**DC:** Direct Current

**HEV:** Hybrid Electric Vehicles

**ICE:** Internal Combustion Engine

# CHAPTER 1

# Introduction

## 1. 1.1 Problem Statement

In today’s world, fuel prices play an important role especially when discussing the economy of countries such as Pakistan. Pakistan is heavily indebted country and is currently facing high fuel prices. Due to these high fuel prices, everything is made expensive, intentionally, or unintentionally. Inflation rate has reached to the highest level since the birth of Pakistan. The cause of these high fuel prices is due to the huge increase in price of crude oil. Crude oil is refined in industries to yield petrol and diesel. During COVID-19, the crude oil prices faced a downfall due to decrease in demand of energy and many businesses were closed temporarily. After the pandemic, the circle of life returned to normal, with increased demand of energy. So as an engineer, the first task was to develop a product that help people to survive in extreme conditions, just like the prevailing situation in Pakistan. Keeping in mind the current situation, the main aim was to design and develop a sustainable product, that is independent of high increase of fuel prices OR may be uses very little amount of fuel to minimize the effect on poor and middle class of society. So, the idea of Hybrid Electric Bike was implemented. Hybrid bikes produce less noise, which helps in making the densest areas like Karachi, Lahore, etc. peaceful. Pakistan is one of the countries among the most polluted one’s in the world, so the factor of pollution needs to be considered and the product should be designed with improved environmental impacts OR environment friendly technology. The product emit less greenhouse gases hence causing less harm to the environment. This was achieved as the bike switches between two drive modes depending upon the driving conditions. Furthermore, the product is designed in such a way that it is applicable for motorbikes of different CC engines and improved energy output is achieved. The focus towards hybrid technology is more rather than electric because in Pakistan there are very few electric charging stations. So, if someone runs out of electric charge, he can continue his journey with petrol without any difficulty. Considering the need of a vehicle with minimum use of petrol, the project ensured to generate maximum energy and power from electric motor to drive the vehicle with minimum burning of fuel to increase fuel efficiency. This innovation will bring a positive impact on environment as well as our economy.

## 2. 1.2 Aim

The main aim was to manufacture a vehicle that generates maximum energy and power from electric motor (Hub Motor) to drive the HEV with minimum burning of fuel to increase fuel efficiency.

## 3. 1.3 Objectives

- To provide easy switching between petrol mode and electric mode
- To extend the range of travelling
- To reduce exhaust emissions
- To reduce fuel consumption
- To reduce the running cost of the vehicle

## 4. 1.4 Overview

The invention of Internal Combustion Engines (ICE) was one of the best inventions in the world in the field of Mechanical Engineering. It was the first engine to drive a vehicle by burning of fuel. Internal Combustion Engines use fuel to burn, and this burning of fuel produces output power. This power is transmitted to wheels using shafts and driving gears that help the vehicle to move. They have long operating range and provide best performance. However, a lot of problems are associated with such engines. First of all, burning of fuel is a major problem that produces greenhouse and poison gases that are harmful for environment. Due to these gases, global warming is increasing day by day. Harmful diseases are discovered due to global warming and disposal of ozone layer. The second problem is fuel consumption. Fossil fuels are near to their extinction, and a technology that is independent of fossil fuels OR has a small dependency, is needed. Internal Combustion Engines use more fuel, hence decreasing fuel efficiency. Keeping in mind the current situation, fuel efficiency is a major concern for almost everyone due to huge increase in fuel prices. So, to look for an alternative that is better than the current technology and will help in conserving natural resources. Thus, Hybrid Electric Bike may serve as a solution and an alternative to conventional petrol bikes as it uses two drive modes, one is same as conventional bike i.e., Internal Combustion Engine drive mode and the other is Electric Mode, driven by electric motor, powered by a battery.

The term hybridization means the vehicle is run OR is powered by two methods, one by Internal Combustion Engine and one by Electric Motor. Internal Combustion Engine uses the power from burning of fuel while Electric Motor use the power stored in batteries. The batteries are not charged by conventional plug-in charging method rather they are charged by regenerative braking and internal combustion engine. The major challenges in designing a hybrid electric vehicle are to manage all the components efficiently including batteries, motor, type of motor, driving cycles, power transmission, charging of batteries, placement of batteries while considering center of percussion of bike, etc. Another challenge is the weight of the bike. By addition of batteries and a motor, the weight of bike will be increased. So, enough power from batteries and electric motor is needed to be able to drive the vehicle with at least one passenger. So, in total, a hybrid bike has to carry the weight of conventional IC engine, batteries, electric motor, bike frame, and passenger. While designing, all these factors should be kept in mind.

Due to increased global warming and harmful effects of exhaust gases from burning of fuel in IC engines, the demand for cleaner alternatives, pollution free transportation, and use of green technology has increased to a great extent. The world is and has moved towards electric power. The use of automobiles in the world has increased significantly therefore the automobile industry is continuously working on improving technology to provide a vehicle that produces no OR minimum pollution. Electric vehicles are in one of them but due to several problems, the technology is not very adaptive. The major problem is complete discharge of batteries and a long time required to recharge them. Thus, a person moving from one place to another needs to plan his trip at least one day prior to the actual day. And if he/she runs out of charging at any place, he is in complete lose-lose situation. The only solution in that case will be a charging station. Refilling petrol requires few seconds or may be a minute but recharging of batteries require few hours. So, your trip is temporarily stopped for few hours without your choice. Therefore, the automotive industry has introduced hybrid technology, by minimizing the use of internal combustion engines and integrating electric motor where required. The world demands a near zero-emissions vehicle and hybrid vehicles are one of them.

The project is to design hybrid electric vehicle by using a hub motor that uses fuel energy from fuel tank to convert it into mechanical power (IC Engine) and uses a hub electric motor that uses electric energy stored in batteries to convert it into mechanical power. The purpose of designing a hybrid bike by using a hub motor is to produce a fuel efficient and less polluting vehicle for poor and middle class. Using hub motor will increase fuel efficiency by two times that of conventional bike.

Basically, there are two drive modes of hybrid vehicles:

1. Petrol Mode
2. Electric Mode

### 1.4.1 Petrol mode

In petrol mode, the vehicle is driven by use of internal combustion engine. Power is generated by burning of fuel (petrol) and is transmitted to rear wheel by use of gears and chain drives. A microcontroller is used to smoothly switch between the two modes. Relays are usually used to obtain this function/objective. Two positions are defined in microcontroller circuit, say as S1 and S2. In the case of bike, when the switch is in S1 position, bike is using power from internal combustion engine and fuel is burnt to drive the vehicle. A thumb throttle is provided that can be used by the rider to control the speed and acceleration of vehicle. In petrol mode, the BLDC motor in front wheel will be in ideal condition/position. Means the controller, while using its sensing ability, will cut off the battery connections with the motor. To achieve this, another relay, imbedded in the controller, is used that just stops the battery from discharging while charging function is obtained, as shown in Figure 1.2. The motor functions in reverse, acting as generator to produce energy to charge the batteries. Petrol mode is used where high power is required, usually outside the city limits. The engine performance depends on its own running capability and the rpm. In short, fuel is used to power the vehicle.

### 1.4.2 Electric mode

In electric mode, the vehicle is driven by use of an electric motor. Power is generated by stored charge in batteries and is transmitted to the front wheel. The power transmission depends on the type of motor used. Hub motors are installed in wheels. They are also known as in-wheel motors because their wheels are mounted over them OR they are mounted inside the wheels. This mode is also controlled by the use of a microcontroller. A relay is used to switch between two positions, as shown in Figure 1.3. The relay shifts the position of switch from S1 (on IC Engine) to position S2 (of electric motor). In this case, the power is consumed by motor from electric energy storage system i.e., batteries and convert it into mechanical power. The IC engine is turned off and the bike runs on electric power from batteries. The power consumption of battery and the speed of bike is also controlled by a throttle. The more the throttle is pushed, the more the power is generated and greater is the discharging of batteries. In this way, fuel efficiency is improved by switching between two drive modes.

The hub motor technology is continuously evolving and is used readily is electric scooters, E-Bikes, electric cars, etc. By development of hub motor, the challenges of mounting the motor externally, providing support to motor, and transmission problems are eliminated. The motor is mounted inside the wheel, in the center axis of wheel hub. Energy is generated as a result of wheel rotation that is used to charge the batteries by use of a small charger. Thus, regenerative technology is employed to minimize energy losses.

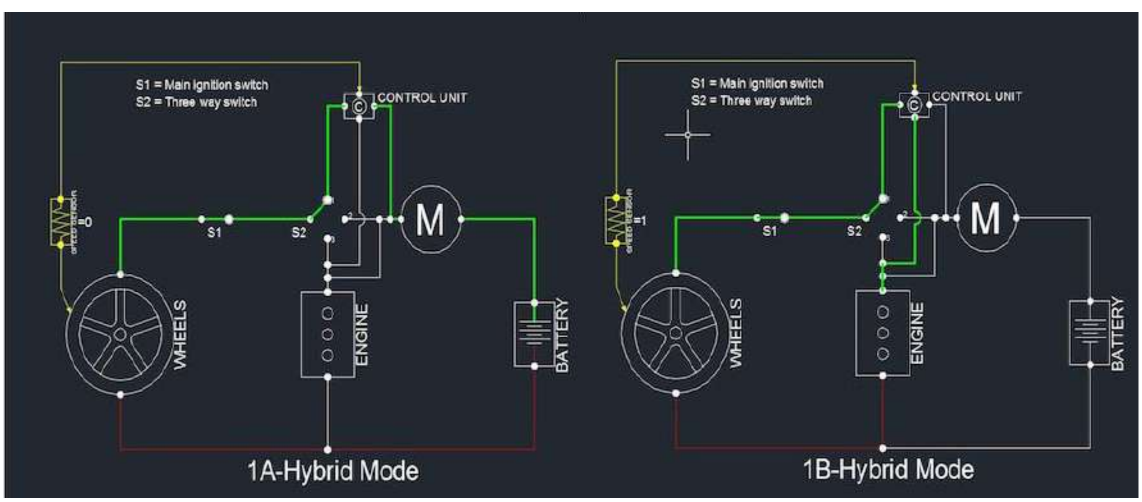


Figure 1. 1 Petrol & Electric Modes Circuit Diagram

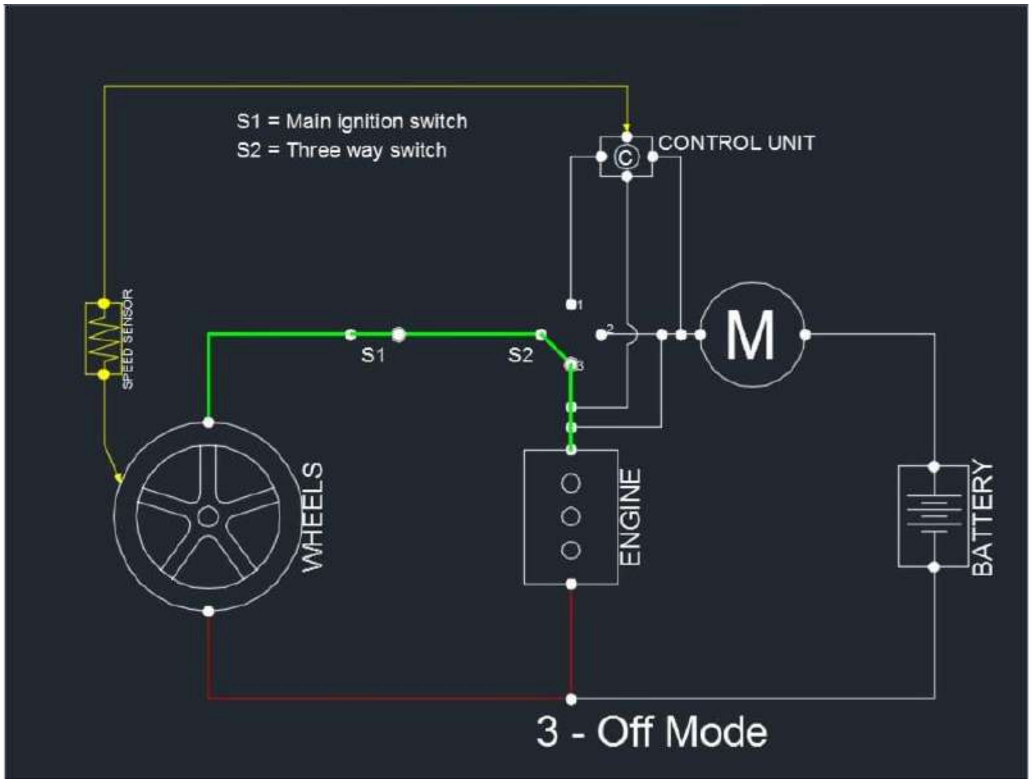


Figure 1. 2 Off Mode Circuit Diagram

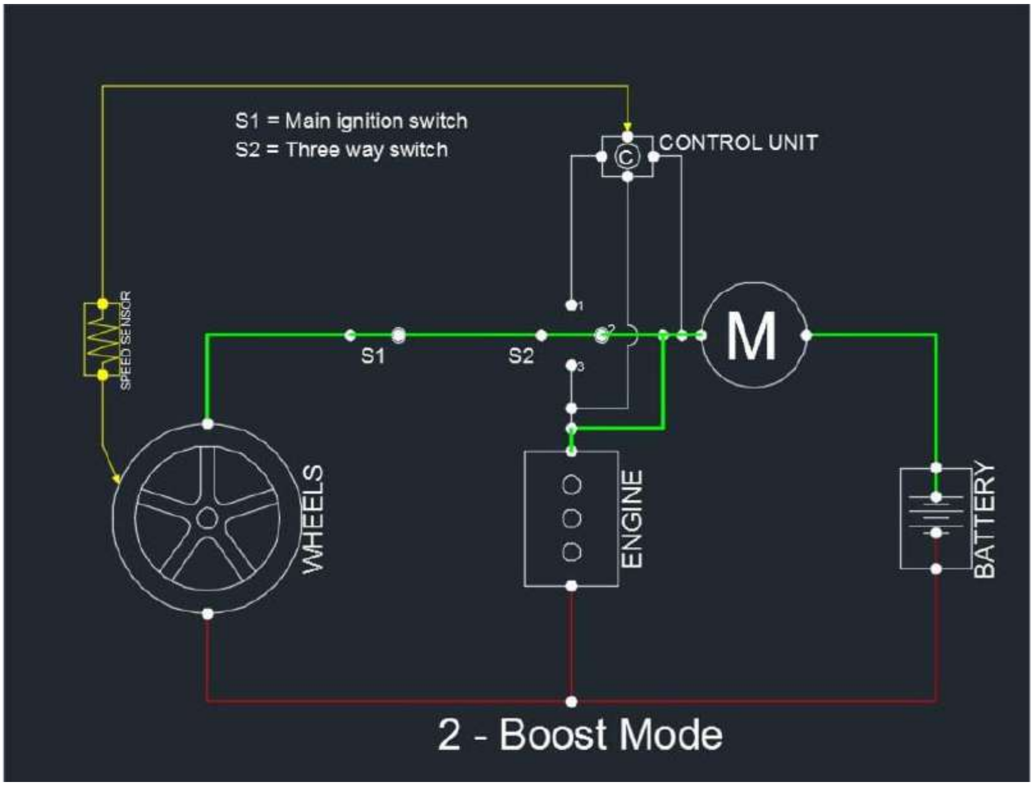


Figure 1. 3 Boost Mode Circuit Diagram

## 5. 1.5 Principle of Hybrid Bike:

The fundamental configuration of this system includes a battery serving as the DC power source. This battery is linked to a hub motor, which is affixed to the front wheel of a two-wheeled vehicle. The motor propels the wheel by rotating it, resulting in vehicle movement. At lower speeds, this method of propulsion is employed. In subsequent stage, an IC engine propels the piston continuously. The engine is linked to the transmission, causing the vehicle to move forward. When the vehicle is to be driven by the IC engine, the motor is turned off. The principle is elaborated in Figure 1.4.

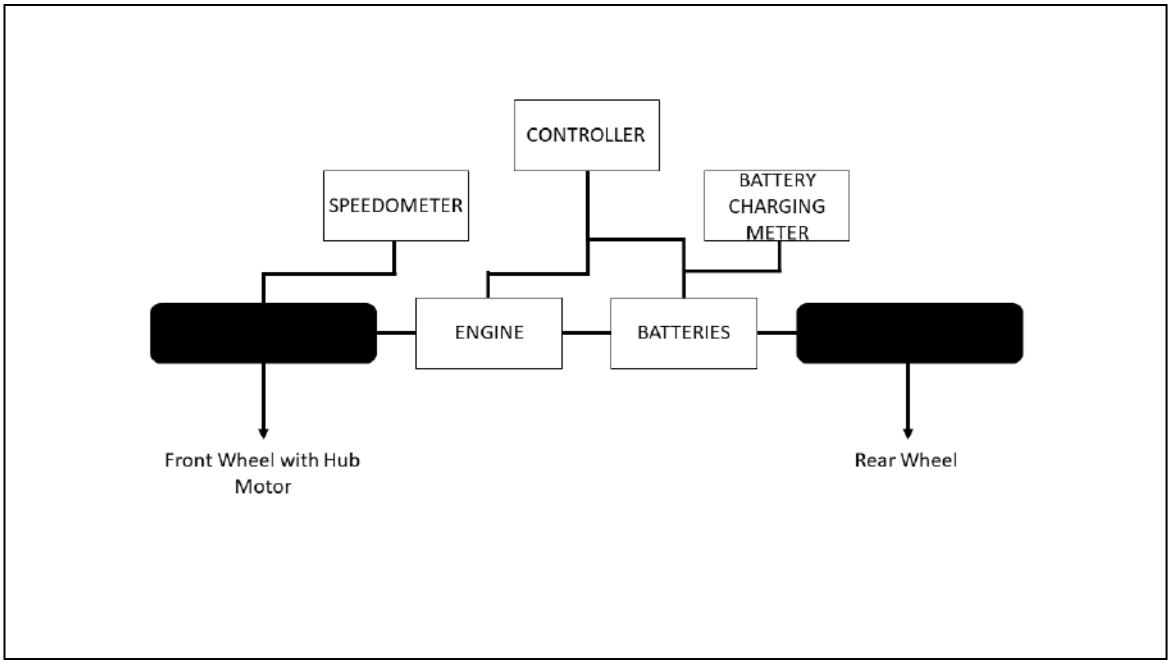


Figure 1. 4 Principle of Hybrid Bike

# 6. 1.6 Components

## 1.6.1 BLDC Hub Motor

BLDC motors are a variant of DC motors that employ an electronic commutator. They are becoming increasingly prevalent as a substitute for traditional DC motors that rely on mechanical commutation, primarily due to their many benefits. The most notable advantages of BLDC motors include their high durability, exceptional efficiency, relatively low weight, and compact size when compared to other types of electric motors. These features are particularly crucial during the design and construction of electric vehicles, as minimizing weight is a top priority.

In this project, a Chinese manufactured BLDC Hub Motor is used of serial no. CA48 350W14115870, as shown in Figure 1.5. The motor is one of the most potent options available in the market and has been specifically designed for installation within the front wheel hub. Its mechanical and electrical specifications are outlined in table 1.1.

**Table 1. 1:** Characteristics of Hub Motor

| | |
|---|---|
| Parameter Value Winding | 10 x 6 (6T), 3-phase |
| Motor Torque Constant (KT) | 1.58 Nm/A |
| Motor Velocity Constant (KV) | 6.00 rpm/V |
| Nominal power at 60 V | 3.01 kW |
| Maximum Power (Instantaneous) | 7.0 kW (~80 ÷ 90 A) |
| Supply Voltage | 24 - 120 V |
| Maximum Current | 50.00 A |
| Hall Sensor | Yes |

Figure 1. 5: Hub Motor CA48 350W14115870

Figure 1. 6 Rotor and Stator

The images displayed above (Figure 1.6) depict the disassembled rotor and stator components of the motor. In BLDC motors, the windings are directly linked to the controller, which modulates the voltage on the appropriate winding through insights obtained from the three Hall sensors located within the motor at intervals of 120 electrical degrees. Despite their advanced control mechanism, BLDC motors exhibit stable torque features that remain constant regardless of rotational speed. The absence of a mechanical commutator renders them more long-lasting and quieter than traditional DC motors, while also allowing them to attain higher velocities.

There are two distinct categories of three-phase motors: outrunners and in runners. Outrunner motors feature a rotating casing, while in runner motors have a rotating interior. The CA48 350W14115870 motor depicted in the images is an outrunner type. Additionally, the windings of the stator are connected in a star configuration.

### 1.6.2 Controller

The controller having serial no. PLT201412 from the Chinese manufacturer Zheijian Tianyu Electronics Co. Ltd, shown in Figure 1.7, is used. This controller is compatible with both BLDC motors (Brushless Direct Current) and PMSM motors (Permanent Magnet Synchronous Motors). The specifications of this controller are listed in table 1.2.

**Table 1. 2:** Characteristics of PLT201412 Controller

| | |
|---|---|
| Rated Voltage Range | 36 V – 48 V |
| Low-Voltage Protection Point | 31 V – 42 V |
| Maximum Power | 350 W |
| Maximum Current | 80 A |
| Maximum Operating Temperature | 50 ºC |
| Mass | 2.2 kg |
| Dimensions (mm) | 220 x 125 x 68 mm |

The lever-based Hall sensor on the controller enables both speed and braking control. Additionally, the controller comes equipped with regenerative braking functionality that allows for battery charging during deceleration, thereby increasing the overall range of the vehicle. Furthermore, the controller is equipped with a comprehensive diagnostic system and several protective measures, including overcurrent protection, overload protection, over-temperature protection, overvoltage and undervoltage protection, and accidental handle lock protection. An image of the PLT201412 controller is presented in Figure 1.7 and the connections of controller are shown in Figure 1.8.


Figure 1. 7 Controller

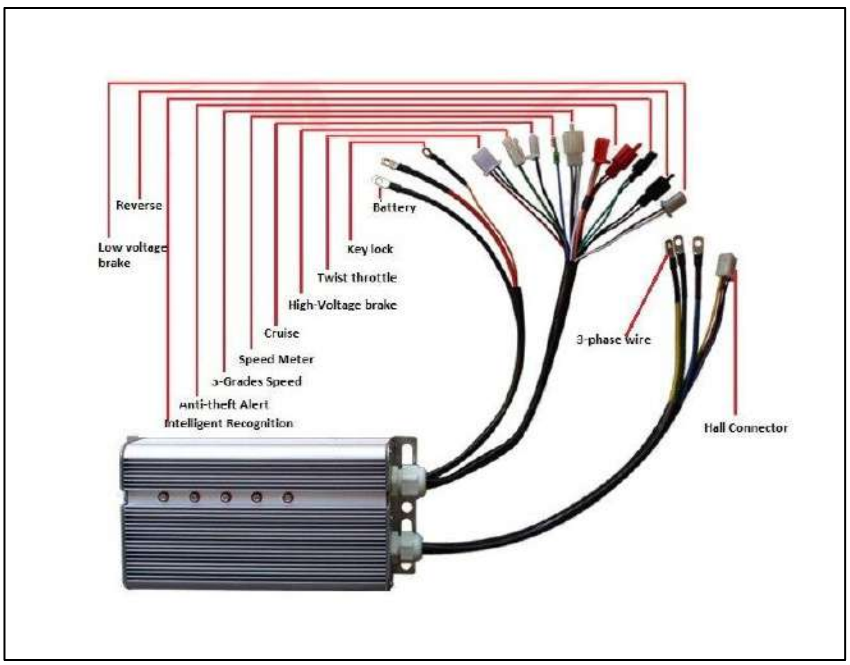

Figure 1. 8 Connections of Controller
(https://www.aliexpress.com/i/32700217784.html)

### 1.6.3 Battery

The Hybrid Electric Vehicle (HEV) incorporates a battery as one of its power sources for vehicle propulsion, particularly in low-power conditions. Batteries are composed of electrochemical cells and serve to provide electrical energy by converting stored chemical energy. Generally, there are two types of batteries: primary batteries, which are disposable, and secondary batteries, which are rechargeable. In the context of vehicles, secondary batteries are preferred due to their reusability.

Currently, there are six major types of rechargeable batteries available, including lead-acid (Pb-acid), nickel-cadmium (Ni-Cd), nickel-metal hydride (NiMH), lithium-ion (Li-ion), lithium-polymer (Li-poly), and zinc-air. The selection of the battery type has a significant impact on the design of the vehicle. Several basic performance characteristics of the battery influence the design considerations, which include the following:

- **Charge/Discharge Ratio (c/d ratio):**

  The charge/discharge ratio refers to the comparison between the input of Ampere-hours (Ah) during charging and the output of Ah during discharging, with no net change in the state of charge. A lower charge/discharge ratio indicates a more efficient battery, as it implies less energy loss during the charging and discharging processes.

- **Round trip energy efficiency:**

  The energy efficiency over a round trip, encompassing a full charge and discharge cycle, is determined by calculating the ratio of the energy output at the electrical terminals of the battery to the energy input. A higher round trip energy efficiency indicates a more favorable performance of the battery, as it signifies a greater proportion of the input energy being converted into usable output energy.

- **Charge Efficiency:**

  The charge efficiency is a metric that quantifies the efficiency of the charging process for a battery. It is calculated by comparing the Ampere-hours (Ah) being deposited internally between the plates of the battery to the Ah delivered to the external terminals during charging. A higher charge efficiency indicates a more efficient battery, as it implies a larger proportion of the input energy during charging is effectively stored within the battery and available for later use.

- **Internal Impedance:**

  Batteries inherently possess internal resistances, which can affect their operational efficiency. The presence of internal resistance prevents the battery from operating at its maximum efficiency. As a result, the power delivered to the load decreases. Therefore, a battery with lower internal resistance exhibits better performance since it can deliver more power to the load, resulting in improved overall efficiency.

- **Temperature Rise:**

  Temperature rise plays a crucial role in battery performance. If a battery exceeds a certain temperature threshold, it can lead to a reduction in its charge capacity. Therefore, a battery that can sustain higher temperatures demonstrates better efficiency and longevity. By maintaining a higher temperature tolerance, the battery can preserve its charge capacity and overall performance over an extended period.

- **Life in number of c/d cycles:**

  Batteries have a finite lifespan, typically measured in terms of the number of charge/discharge (c/d) cycles they can undergo before their performance degrades. A higher value indicating a larger number of cycles reflects a better battery. Batteries with a longer cycle life can sustain their performance and capacity over a greater number of charging and discharging cycles, making them more durable and reliable for prolonged use.

**Table 1. 3:** Average Discharge Cell Voltage in Various Rechargeable Batteries

| Rechargeable Batteries | Average Cell Voltage |
|---|---|
| Lead-acid | 2.0 |
| Nickel-Cadmium | 1.2 |
| Nickel-Metal Hydride | 1.2 |
| Lithium-ion | 3.7 |
| Lithium-Polymer | 3.0 |
| Zinc-Air | 1.2 |

For the project (Hybrid Electric Bike), Lithium-ion battery is used, as shown in Figure 1.9. Battery should be designed in such a way that it can provide sufficient energy to motor to operate smoothly. The load carrying capacity of a motor is dependent on voltage supplied by the battery, but it should not exceed the limit of motor. The more ampere of current, the more life of battery. A battery of 36-48V and 12A is developed by connecting 50 cells, some in series and some in parallel, to achieve the desired output. Voltage generated per cell is 3.7V. Table 1.4 shows battery specifications.

**Table 1. 4:** Battery Specifications

| Parameters | Specifications |
|---|---|
| Voltage | 36-48V |

| | |
|---|---|
| Current | 12A |
| Total Cells | 50 |
| Volt per cell | 3.7V |

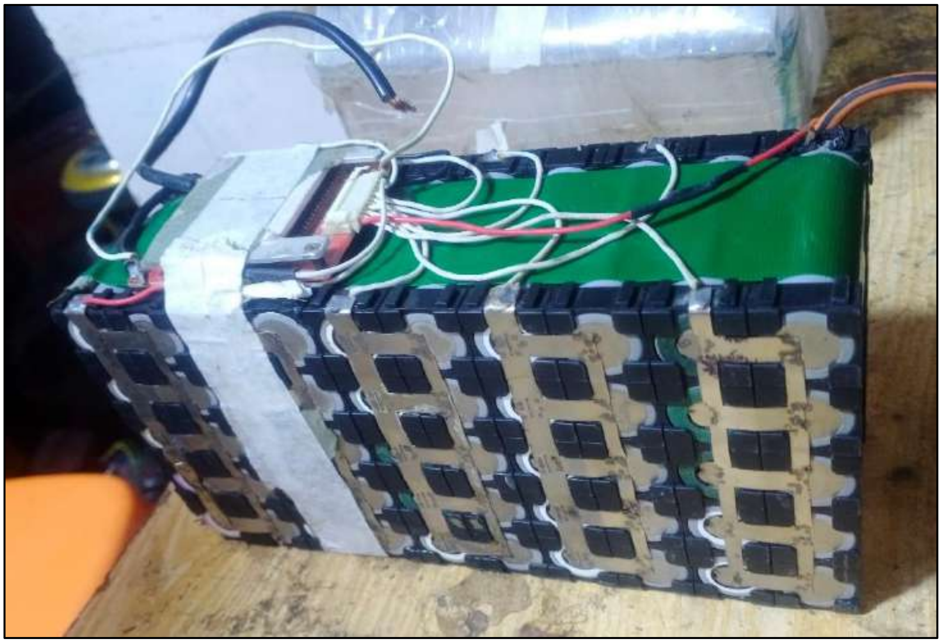

Figure 1. 9: Battery

## 7. 1.7 Thumb Throttle

The electronic thumb throttle is a control mechanism that operates using a button that is pushed forward. When the button is pressed, the thumb throttle increases the amount of voltage supplied, resulting in the motor running faster. The thumb throttle is shown in Figure 1.10.

The thumb throttle typically consists of three sensors, namely XYZ. These sensors are responsible for detecting and measuring the position and movement of the thumb button.

By analyzing the input from these sensors, the thumb throttle can accurately determine the intended speed or acceleration desired by the user.

The XYZ sensors work in conjunction with the electronic circuitry of the thumb throttle to translate the thumb button's position into voltage output. As the button is pushed further forward, the voltage output increases, providing a corresponding increase in power and speed to the motor.

Overall, the electronic thumb throttle provides a convenient and intuitive control mechanism for adjusting the speed of a motor, allowing users to easily modulate the voltage and achieve the desired acceleration or speed.

- **Sensor** – Three position sensor
- **Volts** – 1-7 Volts
- **Type** – Thumb Throttle

Figure 1. 10: Thumb Throttle

# 8. 1.8 Battery Charging Display

The battery charging display is an instrument or indicator that provides real-time information about the battery's voltage during the charging process. The display typically shows the battery voltage in volts (V). Here are some points about the display:

- **Voltage Measurement:** The display system incorporates a voltage measurement circuit or sensor that measures the voltage across the battery terminals. This circuit is designed to accurately sense and convert the electrical potential difference into a voltage value.
- **Voltage Conversion:** The measured voltage is then converted into a readable format for display purposes. This conversion involves scaling and formatting the voltage value appropriately, such as rounding it to a specific number of decimal places and adjusting the unit to volts (V).
- **Display Output:** The converted voltage value is then displayed on the battery charging display using a suitable visual interface. This can be a digital display with numerical digits or an analog display with a needle or bar graph. The display should be easily readable and provide clear and accurate information about the battery voltage.
- **Refresh Rate:** The display system should update the displayed voltage value at a regular interval or in response to changes in the battery voltage. This ensures that the displayed information remains up to date and reflects the actual voltage of the battery during the charging process.


Figure 1. 11: Battery Charging Display

Overall, the battery charging display provides a visual representation of the battery voltage in volts, as illustrated in Figure 1.11. It allows users to monitor the charging progress, voltage levels, and make informed decisions based on the displayed information, ensuring effective and safe battery charging.

## 9. 1.9 Thesis Outline

The thesis is divided into SIX different chapters. Every chapter possesses unique characteristics distinct from the others and is accompanied by an explanation of the essential concepts needed to understand it.

**Chapter 1** includes the introduction of a project that is sub divided into problem statement, objectives, overview, and components of two-wheeler hybrid electric vehicle (HEV).

**Chapter 2** focuses on the literature review and all the research done in the field of electric vehicles and hybrid electric vehicles. Plus, this chapter also explains the evolution of electric and hybrid-electric technologies.

**Chapter 3** describes the methodology of the project. This section explains the tasks that were performed to complete the project.

**Chapter 4** describes the calculations done for measuring the torque and power of motor as well as current and voltage required for battery to smoothly run the hybrid electric bike.

**Chapter 5** describes the installation and performance testing of Hybrid Electric Bike. This section includes speed testing, range testing (battery discharge time in one complete round trip), and efficiency testing (improved fuel efficiency).

**Chapter 6** concludes the project thesis.

# CHAPTER 2

# Literature Review

The wheel hub motor drive boasts several unique benefits over other drive modes. Despite the fact that mature automotive products incorporating wheel hub drives have not yet emerged, wheel hub drive remains a subject of focus in current domestic and international electric vehicle research as an innovative, advanced drive mode. Numerous domestic and foreign scholars have conducted extensive research on the limitations of wheel hub motor drives and proposed a variety of corresponding improvement measures. For instance:

Nagaya et al. [1] addressed the negative impact of unsprung mass on vertical vibration by using the motor mass to create a vibration absorber.

Johansen, Yang et al. [2] decreased unsprung mass by utilizing a unique motor design that converted the motor stator mass into the sprung mass.

Zhao Yan'e et al. [3] transformed the wheel hub motor stator mass from unsprung mass to sprung mass by introducing a vibration reduction mechanism in parallel with the suspension system.

Luo Hong et al. [4] suggested using the entire motor mass as the sprung mass. This involves utilizing the motor mass as the vibration absorber mass in the power-driven system that directly drives the wheel hub motor, without requiring any additional mass.

Shi Tianze et al. [5] designed a unique suspension and steering system for wheel hub motor vehicles. This system features a double-arm front suspension, a torsion beam rear suspension, and a mechanical steering system.

Researchers are actively working to address the challenges associated with wheel hub motor drive through various approaches such as developing high-torque wheel hub motors, integrating and controlling intelligent chassis, and assessing the impact of non-spring mass on vehicle performance. It is expected that in the future, new technologies will be developed to address these challenges and fully leverage the advantages of wheel hub motor drive, making it the preferred drive mode for electric vehicles.

Sharada Prasad N and Dr. K R Nataraj (2014) [6] expressed their concerns about the environment, specifically pollution and fuel conservation. The automobile industry is responding to these concerns by focusing on the production of fuel-efficient and low-emission vehicles with advanced technology. Modern design aims to reduce fuel consumption and exhaust emissions, and one of the most significant innovations in this regard is the Hybrid Electric Vehicle (HEV). By combining a conventional combustion engine vehicle with an electric motor drive, the overall efficiency can be greatly enhanced, resulting in higher fuel efficiency and reduced emissions. The study in question analyzes the combined effort of the independent propulsions, ICE and electric motor, in propelling the vehicle, which is particularly relevant for countries like India. The conclusion drawn was that the ICE will be active in initial pickup, and the electric motor will act in supportive propulsion.

Yasmeen Malik, Vikas Kumar (2017) [7] described that as oil prices continue to rise and environmental concerns become more pressing, there is a need for cleaner and more sustainable energy solutions. The transportation sector is a significant contributor to energy consumption and the emission of harmful pollutants into the atmosphere. Hybrid electric vehicles (HEVs) combine an internal combustion engine with an electric motor, and are becoming increasingly popular due to their ability to achieve similar performance to standard automobiles while significantly improving fuel efficiency and reducing exhaust emissions. The study delves into the different types of hybrid drive trains, including series, parallel, and series-parallel, with a focus on HEV performance using a higher amp-hour capacity battery initially, followed by implementation of a converter circuit to reduce the battery rating in the advanced state. The study also examines various scenarios involving different charging and discharging circuitry for the battery.

Pappuri Hazarathaiah, Y. Ashok Kumar Reddy, P. Vijaya Bhaskara Reddy, and M. Sreenivasulu (2019) [8] designed and built a hybrid electric bike. Hybrid electric vehicles rely on both batteries and an internal combustion engine for propulsion, offering significant advantages over vehicles that are solely powered by gasoline engines. Gasoline engine emissions are a major contributor to air pollution. The objective of the study was to convert an old Bajaj Boxer bike into a hybrid bike by fitting it with an electric wheel hub motor, a battery, and a control system. The researchers found that for low power requirements, battery drive is useful, while for high power requirements, the gasoline engine is the best choice. Hybrid vehicles emit 50% less emissions than conventional vehicles, making them an important tool in reducing pollution without sacrificing efficiency. The vehicle is well-suited for urban areas with high traffic, as gasoline engines are inefficient and waste energy, resulting in unwanted pollution.

N.Boopalan , Marlon Jones Louis and A.K.Nachimuthu (2014) [9] suggested the need for hybrid electric two-wheelers due to issues associated with modern automobiles, including fuel costs relative to mileage, pollution, and low efficiency. The main objective of their project was to design and implement a more efficient and less polluting vehicle. They combined the internal combustion engine of a conventional vehicle with a battery and electric motor to achieve twice the fuel economy of a traditional vehicle. The study presented detailed calculations and analysis, and concluded that the IC engine mode is preferred during high torque requirements, while the vehicle can run on the battery instead of the engine during less load operation. They planned to implement this idea on a Bajaj Spirit bike and conduct performance tests to verify their findings.

Kamatchi Kannan V, Ponmurugan P and Chitra K (2020) [10] highlighted the various advantages of hybrid electric two-wheelers. Hybrid Electric Vehicles (HEVs) are advanced vehicles that can operate using both a battery and electric motor. The motor drives the wheel and also charges the battery when operating as a generator. Hybrid electric two-wheelers have become popular in the market due to their lower $CO_2$ emissions. The main objective of their study was to design and manufacture a hybrid two-wheeler such as a scooty, which can be operated using both petrol and battery power. This would help reduce the cost and complexity involved in the existing hybrid vehicle technology and address the problem of short battery range present in electric bikes. Their study concluded that the battery alone can be used at low-speed conditions where the engine is least productive. In the case of accelerating or slope climbing, the internal combustion engine would provide the extra force required to drive the motor. Battery power is useful for low power requirements, while the gasoline engine must be utilized for high power requirements.

Balasubramani N, Hari Prasath S, Jagadeesh Kumar A, Karna Prakash S, and Karun Prasath D (2018) [11] designed and fabricated a hybrid electric two-wheeler in response to the depletion of fossil fuel resources and the resulting increase in global pollution caused by the growing number of vehicles on the road. The Hybrid Electric vehicle system was chosen as one of the most effective alternative fuel concepts. The team's main objective was to fabricate a hybrid electric two-wheeler that could be driven by both an engine and an electric motor. The front wheel was driven by a hub motor powered by a battery, while the rear wheel was driven by the engine. The performance of the bike was tested in engine mode, electric mode, and hybrid mode, and the results were compared to those of conventional bikes. It was determined that battery drive was suitable for low-power applications, as the engine was least efficient at low speeds. Gasoline engine was more efficient at high speeds and therefore suitable for high-power applications. By operating the bike in both modes at maximum efficiency, the mileage was improved. The harmful emissions were also reduced due to reduced tailpipe emissions, contributing to a reduction in environmental contamination.

Emadi et al. (2008) [12] placed greater emphasis on power electronics as a pivotal technology that facilitates the advancement of plug-in hybrid electric vehicles. They focused on implementing sophisticated electrical architectures to accommodate the growing demands of electric loads. The article provides a concise overview of contemporary trends, future strategies for vehicles, and the role of power electronic subsystems. Additionally, the publication highlights the necessary specifications for power electronic components and electric motor drives crucial for the successful progression of these vehicles.

Daniel (2007) [13] in his work undertook the design, development, and implementation of a series hybrid electric vehicle. While he initially proposed the architecture as a hybrid electric vehicle, he demonstrated the vehicle's efficient operation in electric mode and left the hybrid conversion as a potential future expansion. Prior to constructing the hardware components, he conducted simulations using PSCAD/EMTDC and subsequently validated the simulated results by utilizing the hardware he had developed.

Karen et al. (1999) [14] Texas A&M University has developed V-Elph 2.01, a software package for simulation and modeling. V-Elph, which uses the MatLab/Simulink graphical simulation language, is compatible with various computer platforms. The researchers also explained the methodology used in designing vehicle drivetrains with the V-Elph package. The simulation software was employed to design different types of drivetrains, including an electric vehicle (EV), a series hybrid electric vehicle (HEV), a parallel HEV, and a conventional internal combustion engine-driven drivetrain. The simulation results, which covered factors like fuel consumption, vehicle emissions, and complexity, were thoroughly compared and discussed for each vehicle configuration.

Kuen-Bao (2008) [15] provides a comprehensive description of the mathematical modeling, analysis, and simulation of an innovative hybrid powertrain used in a scooter. This hybrid powertrain stands out for its utilization of a split power system, consisting of a one-degree-of-freedom (dof) planetary gear-train (PGT) and a two-dof PGT, which combine the power generated by a gasoline engine and an electric motor. The research establishes detailed models for the components of the hybrid electric scooter using the Matlab/Simulink environment. The performance of the proposed hybrid powertrain is evaluated by applying the developed model to four different driving cycles. The simulation results confirm the operational capabilities of the suggested hybrid system.

# CHAPTER 3

# Methodology

## 3.1 Phase-1 (Analyzing components of Hub motor)

The first phase includes the testing and analyzation of hub motor and its components. Based on testing and analysis, it was determined that designing a BLDC hub motor is an iterative process that involves numerous unknown parameters. An essential aspect of this process is ensuring that the electromagnetic torque generated by the hub motor is strong enough to propel an electric bicycle or bike. Typically, an electric bike requires a rated torque of around 15 Nm. As a part of integrated device for electric bikes, a 900 W, 3-phase, 12-pole/18-slot BLDC hub motor with an exterior-rotor configuration is used to meet the requirement. Figure 3.1 shows the cross section and geometrical parameters of hub motor.

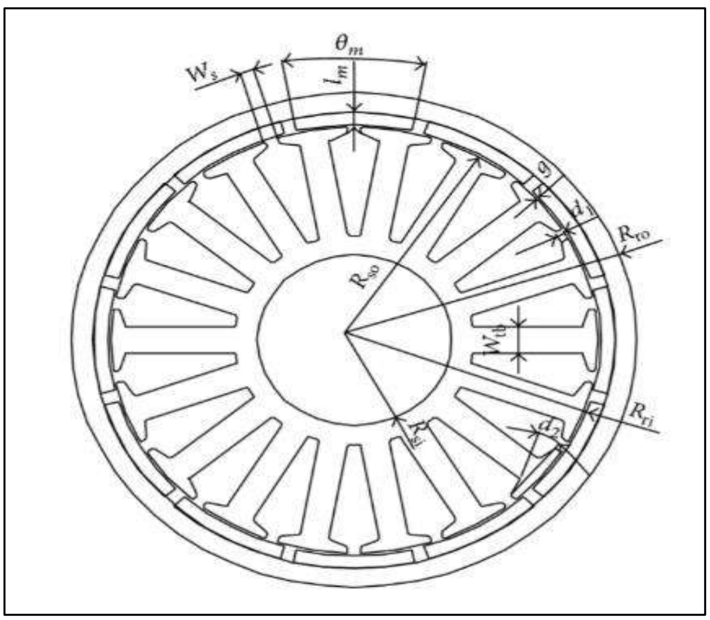


Figure 3. 1 Cross Sectional View of Hub Motor

The chosen permanent magnet for the BLDC hub motor is the neodymium-iron-boron (NdFeB) BNP12. The schematic representations of the winding configurations for each phase of the motor are displayed in Figure 3.2 and Figure 3.3.

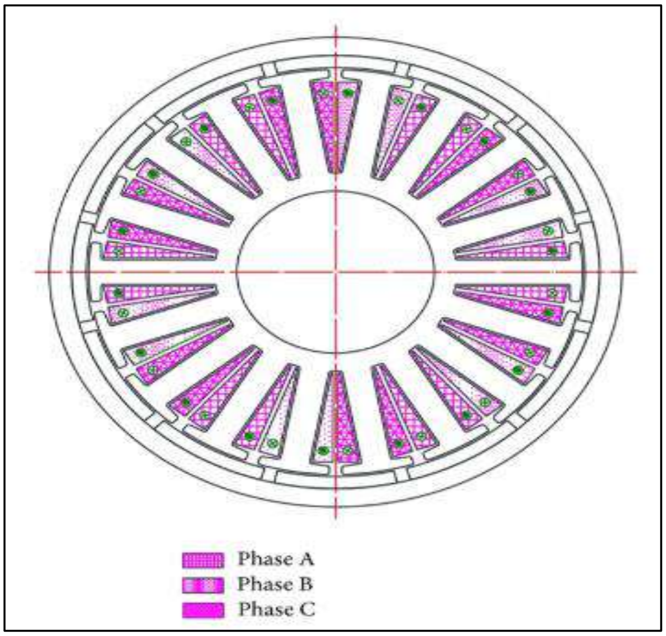


Figure 3. 2 Winding Configuration

Figure 3. 3 Internal Configuration of Hub Motor

Table 3.1 shows the rated conditions, magnet's material properties, and design results for the exterior-rotor BLDC hub motor.

**Table 3. 1**: Rated Conditions and Magnet's Material Properties

| | |
|---|---|
| Number of phases | 3 |
| Number of magnetic poles | 12 |
| Number of armature slots | 18 |
| Inner radius of rotor | 50 mm |
| Outer radius of rotor | 60 mm |
| Number of coils per armature tooth | 54 |
| Inner radius of stator | 20 mm |

| | |
|---|---|
| Outer radius of stator | 50 mm |
| Rated phase current (ampere) | 12 A |
| Power (watt) | 900 W |

## 3.2 Phase-2 (Working of Hall sensor)

The Hall sensor is a crucial component in a hub motor, responsible for maintaining the motor's continuous operation by continuously changing the polarity of magnets. When the battery is connected and the throttle is engaged, the Hall sensors detect the polarity of the stator magnets and subsequently change the polarity of the rotor magnets. The Hall sensor, shown in Figure 3.4, operates by measuring the changing voltage produced when the device is placed in a magnetic field. Essentially, the Hall effect sensor detects when it enters a magnetic field and can sense the position of objects based on this detection. Figure 3.5 illustrates the hall sensor in CA48 350W14115870 Hub Motor.

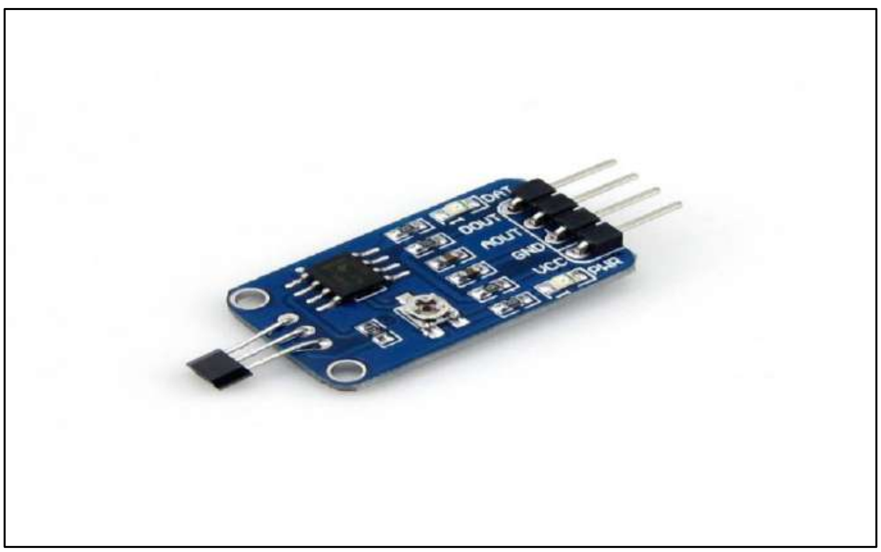

Figure 3. 4 Hall Sensor

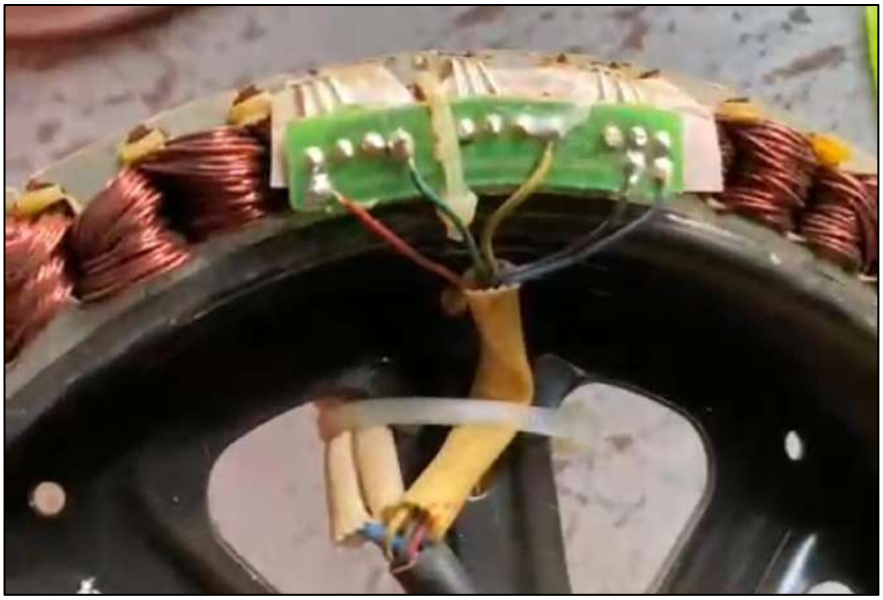

Figure 3. 5 Hall Sensor in CA48 350W14115870 Hub Motor

## 3.3 Phase-3 (Testing and Problems of Hub motor)

In order for a vehicle to function effectively, there are various processes and mechanisms that must work together seamlessly as an integrated system. To achieve the desired goals, extensive research was conducted to determine which technologies, components, brands, and models should be employed. In this section, an outline of the testing procedures utilized for the Hub Electric Motor project is presented.

The hub motor requires 900 W power, a minimum voltage of 36V to operate in standard conditions. An initiative was taken to carry out testing in our university labs but were failed due to lack of particular equipment required for testing. The main purpose of testing was to measure the brake power and torque of motor to analyze the difference between companies defined and practically measured brake power and torque. Second thing was it would enable us to calculate how much weight it can carry when installed in a bike, keeping in mind the weight of bike as well as the weight of person driving the bike. The next step is to design a hub motor with such specifications that would enable us to carry the weight of a person and drive the bike efficiently. But going through several research papers, a lot of disadvantages and problems regarding the use of hub motor for hybrid vehicles were found. Some are enlisted below:

1) The integration of the motor into the wheel hub results in increased unsprung weight, which can negatively impact ride quality and handling.
2) Hub motors also generate more heat, which can cause reliability issues and reduce the overall lifespan of the motor.
3) Frequent motor winding damage due to excessive heating caused by overloading or sudden increase in speed.
4) No direct cooling system for motor to prevent high temperature rises.
5) Sensor damage due to excessive heating.
6) Frequent repairing and maintenance required.
7) Less torque due to absence of gears (direct driving).
8) Not enough power generated to drive heavy loads.
9) Costly as compared to simple Electric OR normal IC Engine Bikes.

## 3.4 Phase-4 (Key criteria/principles)

In the process of developing a new technology or product, it is crucial to maintain a clear understanding of the desired outcome throughout the design phase. To achieve the desired end results, key design criteria must be proposed from the outset. By establishing a hierarchy of essential design criteria and their rationale, the most appropriate design process can be established. Additionally, the design criteria enable the creator to prioritize tasks and effectively manage their time to achieve the defined project goals. The initial phase of the Hybrid Electric Vehicle project involved defining and prioritizing the design criteria in order of importance. With these criteria conceptualized, the project could be assessed at every step to ensure that the priorities and objectives were met. The following are the key design criteria/principles that were defined and ranked in order of priority to meet the goals of the Hybrid Electric Vehicle project. Some key criteria for design is shown in table 3.2.

**Table 3. 2:** Key criteria for design

| Key Criteria | Description |
|---|---|
| Functional | The functionality of the Hub Electric Motor project pertains to the ability of the motorcycle and all its individual systems to work in harmony at their full capacity. The motorcycle must be capable of reaching and maintaining a reasonable speed of 80 km/hr. Furthermore, it should be able to utilize alternative power sources for travel. The motorcycle should have the ability to recharge or refuel at any location or time convenient to the user. |
| Efficient | The efficiency of the Hub Electric Motor project must be measurable so that a comparison can be made with the original factory version of the motorcycle, allowing conclusions to be drawn. |
| Affordable | The project should aim to utilize second-hand, salvaged, or reasonably priced parts wherever possible to minimize the |

| | |
|---|---|
| | overall investment. The objective is to create a product that is affordable on a global scale. |
| Available | The technology used in the project should be accessible to the general public and readily available so that project timelines can be met without delays. |

# CHAPTER 4

# Design and Calculations

## 4.1 Designing

This section describes the design considerations and features of a hybrid bike.

- **Braking System and Motor Placement:** The chosen hub motor for the bike does not have an in-built braking system. This constraint makes it impractical to install the motor in the rear wheel since there would be no mechanism for braking. As a result, the decision was made to install the hub motor in the front wheel, as shown in Figure 4.1.

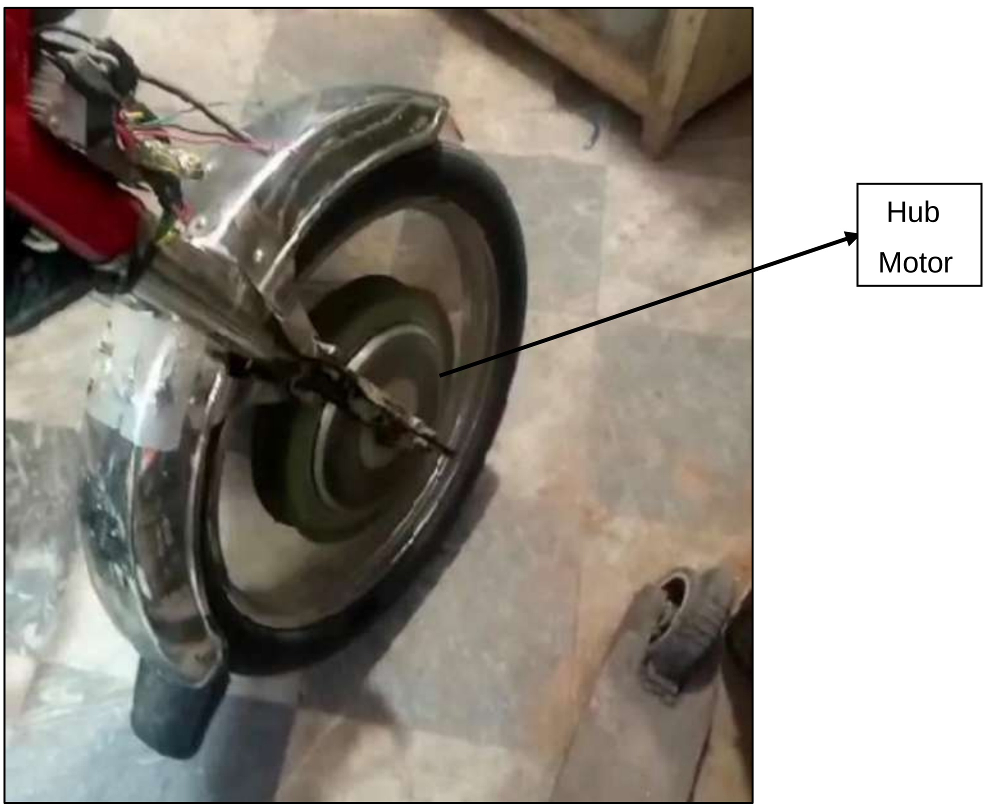


Figure 4. 1: Hub Motor in front wheel

- **Motor and Sprocket Compatibility:** The motor material is not compatible with welding to the sprocket. This means that removing the chain-sprocket assembly would render the internal combustion (IC) engine useless. Therefore, the chain-sprocket assembly is retained, and the hub motor is installed separately in the front wheel.

- **Drive Modes:** To offer versatility, an ON/OFF switch is provided to shift between two drive modes: Petrol and Electric. This allows the rider to choose between using the IC engine or relying solely on the electric power provided by the hub motor.
- **Battery and Controller Placement:** The battery is designed to meet the power and torque requirements of the motor to propel the bike. It is installed in the tools compartment along with the controller. This placement ensures easy access and efficient use of space.
- **Battery Charging and Display:** A display is incorporated into the bike, along with the speedometer, to indicate the battery's charge level in terms of volts. This feature is essential as it provides the rider with crucial information about the battery's charge status, enabling them to plan their rides accordingly.
- **Throttle and Speed Limit:** A throttle is positioned next to the IC engine throttle. It allows the rider to control the electric power output from the hub motor. The throttle is set to restrict the speed to not exceed the defined limit of 40 km/h. This ensures safe and controlled operation of the hybrid bike.

Overall, the design of the hybrid bike considers the limitations of the hub motor, the need for a braking system, compatibility with the existing IC engine setup, battery power requirements, convenient placement of components, and crucial information display for the rider. These considerations aim to provide a functional and efficient hybrid bike that combines the benefits of both petrol and electric power modes.

## 4.2 Hub Motor Calculation

Motor specification

RPM = 500

Volt = 36 – 48 V

Power = 900 W

Power equation,

$$\mathbf{Power = I * V}$$

Where,

V = 36 -48 V

P = 900 W

So, current

$$I = 900/36$$

$$= 25 \text{ A}$$

To find the torque of the hub motor,

$$\mathbf{P = 2\pi NT/60}$$

$$T = P \times 60 / 2 \times \pi \times N$$

$$T = 900 \times 60 / 2 \times \pi \times 500$$

T = 17.18 N-m

Torque of the wheel hub motor **T = 17.18 N-m**

## 4.3 Power Required to Propel the Vehicle

Therefore, the initial torque required to propel the vehicle will be <17.18 N-m.

T =16 N-m

P = 2 x π x N x T / 60

P = 2 x π x 500 x 16 / 60

**P = 837 W**

Hence, the power required to propel the vehicle is 837 W, which is just below our motor specification of **900 W**. So, the design is safe.

## 4.4 Battery Requirement

Volt = 36 - 48 V

Total cells = 50

Volt per cell = 3.7 V

Ampere / Current = 12 Ah

## 4.5 Arrangement Of Cells In Battery

We connected 5 cells in parallel (in each row) and then connected all the cells in series to make a battery producing 36 Volts and 12 Amperes, as shown in Figure 4.2.

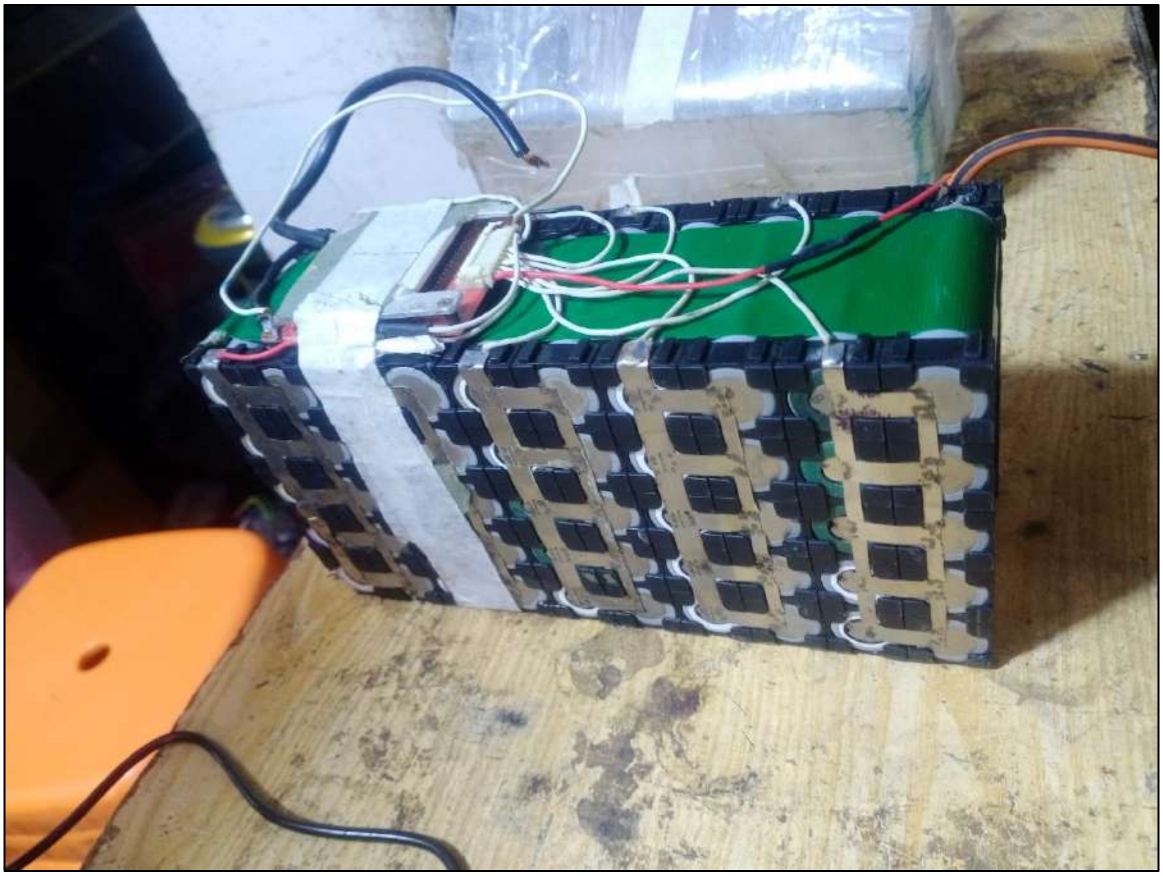

Figure 4. 2: Series and Parallel Connection of Battery

### 1. 4.5.1 Series Connection

The provided text explains the concept of connecting cells in series. In electrical circuits, a cell refers to a single unit that generates electrical potential difference (voltage) through a chemical reaction. When multiple cells are connected in series, their positive and negative terminals are connected in a chain-like fashion, with the positive terminal of one cell connected to the negative terminal of the next cell, and so on.

By connecting cells in series, the overall voltage of the battery is increased. This is because the individual voltages of each cell add up to create a larger total voltage. For example, if two cells each have a voltage of 1.5 volts and they are connected in series, the total voltage across the combination would be 3 volts (1.5 volts + 1.5 volts).

It's important to note that connecting cells in series does not affect the ampere rating or current capacity of the battery. The ampere rating represents the amount of current that a battery can deliver. When cells are connected in series, the total ampere rating remains the same as that of a single cell.

To summarize, connecting cells in series allows for an increase in overall voltage while maintaining the same ampere rating. This is a common technique used in various applications that require higher voltages, such as in electric vehicles, and power systems.

## 2. 4.5.2 Parallel Connection

In electrical circuits, when cells are connected in parallel, the positive terminals of all the cells are connected together, and the negative terminals are connected together.

By connecting cells in parallel, the overall voltage of the battery remains the same as that of a single cell. This is because the voltage across each individual cell is the same, and when they are connected in parallel, the total voltage across the combination does not change.

However, connecting cells in parallel increases the overall ampere rating or current capacity of the battery. The ampere rating represents the amount of current that a battery can deliver. When cells are connected in parallel, the individual ampere ratings of each cell add up to create a larger total ampere rating. For example, if two cells each have an ampere rating of 1 ampere and they are connected in parallel, the total ampere rating would be 2 amperes (1 ampere + 1 ampere).

Connecting cells in parallel is beneficial in situations where high current levels are required. By increasing the overall ampere rating, a parallel connection allows the battery to deliver more current to power devices or systems that demand greater electrical loads.

To summarize, connecting cells in parallel maintains the same voltage while increasing the overall ampere rating of the battery. This configuration is commonly used in applications where high current capabilities are needed.

## 4.6 Effect of Battery Ampere Hours on Duration Of Battery

The duration of a battery cycle, or how long a battery lasts, is primarily influenced by its capacity, which is typically measured in ampere-hours (Ah). When a device is connected to a battery, it draws a certain amount of current to operate. The current draw is measured in amperes (A). The duration of the battery cycle is affected by the current draw and the capacity of the battery. The capacity of the battery and the current draw of the device connected to it are the key factors in determining how long the battery will last.

## 4.7 Load carrying capacity

The maximum load that a motor can carry/can drive is = 220 kg. The load carrying capacity of the motor is dependent on voltage supplied within the defined limits. The voltage limits are from 36 – 48V. So, the voltage should not be less or greater than limits.

# CHAPTER 5

# Installation and Performance Testing

The installation involves following steps:

## 5.1 Hub motor kit compatibility

It is crucial to choose a hub motor kit that is specifically designed and compatible with a hybrid bike. Considerations include ensuring that the kit's wheel size matches the bike's wheel size, as well as selecting a motor with an appropriate power rating that aligns with the desired performance of the bike. Additionally, the kit should be compatible with the battery capacity that will be used.

## 5.2 Battery pack

Selecting a lithium-ion battery pack that is compatible with the chosen motor kit is important. The battery pack should have the necessary voltage and capacity to power the motor effectively and provide the desired range for the hybrid bike. In this project, a 36V, 12Ah lithium-ion battery is employed, as shown in Figure 5.1. The decision to use this specific type of battery is driven by its high energy density, low self-discharge rate, and minimal maintenance requirements. The chosen location to house the battery is beneath the seat, utilizing the available free space.

Figure 5. 1: Battery Pack

## 5.3 Controller operations

The motor kit should include a controller, as shown in Figure 5.2, which is responsible for regulating the motor's operations. The controller manages the power output, speed, and other parameters of the motor. It is crucial to ensure that the selected motor kit includes a suitable controller that can be integrated with the hybrid bike's electrical system.


Figure 5. 2: Controller

## 5.4 Throttle

Choosing an appropriate throttle is essential for controlling the speed of the motor. The throttle allows the rider to vary the power output of the motor based on their input. It is important to select a throttle that is compatible with the motor kit and provides smooth and responsive control over the motor's speed. The thumb throttle with required specification is shown in Figure 5.3.

Figure 5. 3: Thumb Throttle

## 5.5 Torque arm

A torque arm is used to ensure that the motor is securely attached to the bike's frame, preventing any rotation or movement that may occur due to the motor's torque. It is essential to have a torque arm included in the kit to provide a reliable and safe connection between the motor and the bike's frame.

## 5.6 Attaching the hub motor

Start by attaching the hub motor to the bike's frame, as shown in Figure 5.4. Ensure that the motor is positioned correctly and securely. The exact method of attachment may vary depending on the specific motor and bike design.

Figure 5. 4: Hub Motor in Front Wheel

## 5.7 Installing the hub motor on the front wheel dropout

To properly fit the hub motor, release it onto the dropout slot of the front wheel. The dropout slots are the openings on the bike's fork where the axle of the wheel fits. Carefully align the hub motor with the dropout slots and make sure it fits snugly, as illustrated in Figure 5.4.

By considering these factors and ensuring that the chosen hub motor kit includes all the necessary components such as the battery pack, controller, throttle, and torque arm, you can select a kit that is specifically designed for a hybrid bike and meets your requirements for power, range, and compatibility.

## 5.8 Battery Range

**Battery range in hours**

When the motor operates at maximum power, the calculation for battery range within a specific time unit is as follows:

Range [h] = Battery Capacity [Ah] / Motor Rated Current [A]

Ir = Motor Rated Current = Pr / Ur = 12 A

Pr = Motor rated power = 900W

Ur = Battery Rated Voltage = 48 V (from manufacturer)

So, the battery can last up to 38 minutes with the motor working at full power.

**Battery range in km**

To determine the range per unit of distance, assuming the bike maintains a constant speed at its maximum level, we can proceed as follows:

Ug = Range [km] / Range [h] => Range [km] = Ug x Range [h]

Ug = 20 km/h (max speed)

T = 0.64 h (range in hours)

So, the bike can travel 8-10 km without charging, provided it travels at full speed.

Figure 5. 5: Hybrid Electric Bike

# Conclusion

HEV technology is indeed a promising solution to address the challenges of fuel efficiency and environmental pollution. The use of both petrol and battery power sources allows for optimal efficiency at different driving conditions, resulting in reduced fuel consumption and emissions. Furthermore, the hybrid system's regenerative braking technology helps to recover energy that is typically lost during braking, further improving fuel efficiency.

The development of a hybrid bike with minimal additional weight is a challenging task, as it requires careful integration of multiple subsystems such as the engine, motor, battery, and control system. However, the benefits of such a vehicle are significant, particularly for medium distance travel in urban areas with high traffic.

As the project continues, it is important to focus on the optimization of the various mechanisms for decision making and control. This includes the development of advanced algorithms for hybrid power management, as well as the integration of sensors and other technologies to improve vehicle performance and efficiency. Additionally, the project should consider the use of alternative energy sources, such as solar panels, to further reduce the reliance on fossil fuels.

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