Design and Fabrication of the Hybrid Motorbike: A Step Towards Green and Sustainable Transport Systems in the Future

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Abstract

In this research work the design and fabrication of a hybrid motorcycle is presented. The hybrid electric motorbike is an expression of a sustainable future and a commitment to offering riders a first-rate, responsible form of mobility. The designed motorbike contributes to the two-wheeler industry by embracing green technology and incorporating sustainable solutions, providing a thrilling experience while safeguarding the environment. The motorbike's hybrid powertrain system is its brains. The combination of an internal combustion engine and an electric motor gives the rider the choice to employ one or both power sources simultaneously. It is appropriate for a variety of riding circumstances and preferences because of its mobility, which enables an increased range and optimal performance. By combining an internal combustion engine and an electric motor, this hybrid motorcycle can drastically lessen its impact on the environment. In heavily crowded locations, the electric motor reduces air and noise pollution by enabling zero-emission operation during low-speed or urban riding.

I. Introduction

The history of hybrid electric motorbikes can be connected to growing environmental concerns, especially vehicle emissions and the limited supply of fossil fuels. The idea of integrating electric and internal combustion engine technology into one vehicle originated as the globe looked for more economical and environmentally friendly transportation options. As more potent and high-in-energy lithium-ion batteries emerged in the early 2000s, interest in electric bikes (or "e-motorcycles") began to grow. These motorbikes provided a more environmentally friendly and quieter alternative to conventional gasoline-powered models, but they had issues with range and charging infrastructure [1, 2]. Companies like Toyota with their Prius and Honda with their Insight paved the way for hybrids, showcasing the potential benefits of combining electric and gasoline power sources [3]. As electric motorcycles continued to improve in performance and efficiency, manufacturers began exploring the idea of incorporating hybrid technology into two-wheelers. The goal was to leverage the advantages of both electric and gasoline power sources to create a more versatile and practical vehicle. Advances in battery technology, such as higher energy density and faster charging capabilities, allowed for more viable electric powertrains. This progress further fueled the development of hybrid electric motorcycles, as it provided a way to combine the strengths of both electric and internal combustion engines [4]. The growing awareness of climate change and environmental impact pushed the automotive and motorcycle industries to find sustainable solutions. Governments and consumers alike started demanding more eco-friendly vehicles, creating a market for hybrid and electric motorcycles. Motorcycle manufacturers and startups began investing in research and development to create hybrid electric prototypes and concepts [5]. They aimed to find the right balance between electric and gasoline power, optimizing efficiency and performance. Manufacturers began displaying hybrid electric motorbike designs at major motorcycle fairs and displays, igniting interest among enthusiasts and the industry as a whole [6, 7]. As battery technology improved and consumer interest in eco-friendly vehicles grew, some companies began commercializing hybrid electric motorcycles. These vehicles offered riders the flexibility of using either electric power for short commutes or gasoline power for longer journeys [8, 9]. Today, the hybrid electric motorbike stands as a symbol of innovation, sustainability, and adaptability. It represents the continuous efforts to reduce carbon emissions, explore alternative energy sources, and reimagine the future of transportation. As technology continues to advance, we can expect hybrid electric motorbikes to play an increasingly significant role in shaping the future of two-wheeled transportation [10, 11]. The motorcycle industry is a dynamic and varied one that serves a variety of customers and interests. Motorcycles are well-liked because of their adaptability, effectiveness, and the sense of freedom they give their riders. These are the most fundamental and adaptable motorcycles, good for both leisure and daily transportation. For varied skill levels and riding requirements, they are normally offered with a variety of engine capacities and have a comfortable upright riding position [12, 13]. Motorcycle manufacturers from around the world and in different regions compete fiercely for market share. Japanese manufacturers like Honda, Yamaha, Suzuki, and Kawasaki are well-known internationally and provide a wide selection of motorcycles that are suited to various market groups. American manufacturers with a heritage-inspired design aesthetic, like Harley-Davidson and Indian Motorcycle, are well known for their cruisers. Premium motorcycles from European manufacturers like BMW, Ducati, Triumph, and Kawasaki are well known. These models include sport, adventure, and touring bikes. Manufacturers from China and India are also establishing themselves as key participants, providing inexpensive motorcycles with rising performance and quality. Through education, public awareness campaigns, and the creation of modern safety technologies, governments, and safety organizations continue to put their attention on enhancing rider safety [14, 15]. Environmental issues, tougher emissions laws, and adjusting to the move towards electric transportation present difficulties for the motorbike sector. However, chances for expansion and diversification are presented by the rising popularity of motorcycle touring, adventure riding, and customization. Future trends in motorbike ownership may be influenced by the growth of ride-sharing and subscription-based ownership models [16-18]. Overall, technical improvements, shifting consumer preferences, and initiatives to provide more environmentally friendly transportation options all contribute to the motorbike market's vibrant and ongoing growth. Innovation, environmental consciousness, and a dedication to giving riders safer and more enjoyable experiences on the roads are likely to influence the industry's future [19]. In recent years, the market for electric motorcycles has seen significant growth and development. Electric motorcycles have come to light as an achievable way to lessen carbon emissions and advance cleaner mobility as the world moves towards environmentally friendly and sustainable transportation solutions. In comparison to their gasoline-powered equivalents, electric motorcycles are less expensive to operate and maintain. Since electricity is typically less expensive than petrol, fuel costs are reduced. The market for electric motorcycles is expected to grow as technology improves, the availability of charging stations increases, and more people choose environmentally friendly modes of transportation. Electric bikes are expected to be a key factor in determining the direction of urban mobility and personal transportation as the industry develops, helping to create a cleaner and more sustainable transportation environment [20]. When an internal combustion engine (ICE) and an electric motor are combined in one motorcycle, this is referred to as hybridization. The motorcycle can profit from the advantages that both power sources have to offer thanks to this combination. As the electric motor helps to provide extra power when needed, hybrid motorcycles often have a smaller ICE than standard motorcycles. An external power source or regenerative braking, where energy is collected during deceleration, can be used to charge the battery pack that powers the electric motor. Hybrid motorcycles are more environmentally friendly and have better fuel efficiency than conventional motorcycles. Acceleration power is increased by the electric motor, relieving pressure on the ICE and improving overall performance [21]. Additionally, hybrid motorcycles may have features like an electric-only mode that, in some circumstances, enables emission-free, silent running. Compared to hybrid automobiles, hybrid motorbikes are still relatively uncommon, but certain manufacturers and startups have started investigating and producing hybrid models. These bikes frequently use cutting-edge technologies, such as sophisticated management systems that optimize power distribution and battery charging, to handle the integration of the two power sources. By developing and promoting hybrid-electric technology, the motorcycle industry and the transition to purely electric motorcycles will be embraced by people who buy hybrids. Using hybrid technologies, two of the biggest problems with purely electric vehicles can be resolved. The long recharging times and range concerns motorcyclists. A rider won't have to worry about the length of their trip if they arrive at their destination using just the stored energy in their batteries, or about finding charging stations and waiting many hours for their motorbike to recharge [22, 23]. Since hybrid motorbikes are still relatively new on the market, consumers may be unaware of their advantages and are unsure how they work. It's essential to inform potential customers about hybrid technology's benefits to boost consumer acceptance and demand. Overcoming these challenges requires continued technological advancements, cost reductions, infrastructure development, and consumer education. As the market evolves, these barriers may gradually diminish, leading to increased adoption of hybrid motorbikes.

The goal of this research is to design and fabricate a hybrid electric motorcycle that can satisfy consumer needs and has the potential to offer several solutions to the challenges faced by conventional motorcycles. This hybrid motorbike can significantly reduce environmental impact by combining an electric motor with an internal combustion engine. The electric motor allows for zero-emission operation during low-speed or urban riding, reducing air and noise pollution in densely populated areas. The ICE provides the necessary power for high-speed riding or when the battery charge is depleted, offering versatility without compromising performance. Combining an electric motor and an ICE enables hybrid motorbikes to achieve better fuel efficiency than conventional motorcycles. The electric motor assists during acceleration and low-speed riding, reducing the load on the ICE and improving overall efficiency. Additionally, this hybrid motorbike offers the flexibility of both electric and internal combustion power sources. Riders can choose to ride in electric mode only for short urban trips, benefiting from reduced noise and emissions. For longer rides or when the battery charge is low, the ICE provides the necessary power, eliminating concerns about range limitations or the availability of charging infrastructure. This motorcycle would enable users to adjust to electric technology while still having the security of an internal combustion engine as a backup by slowly applying electric power. This smooth transition can help reduce issues like range anxiety and physical difficulties. Integrating an electric motor in this hybrid motorbike can also enhance performance. The instant torque provided by the electric motor improves acceleration and responsiveness, resulting in a more engaging riding experience. Additionally, the electric motor can assist the ICE during acceleration, boosting power and performance.

II System's components and materials used

A. System design

To ensure smooth operation and top performance, many components must be integrated and coordinated when designing a system for a hybrid electric motorcycle. A high-level description of the system design for a hybrid electric motorcycle is given below. A hybrid electric motorbike combines the power of an internal combustion engine (ICE) with an electric motor to provide improved fuel efficiency and reduced emissions. This whole system schematic circuitry and CAD model of a hybrid electric motorbike involves the integration of components from both the ICE and electric drivetrain systems and are shown in **Fig.1** and **Fig.2** respectively.

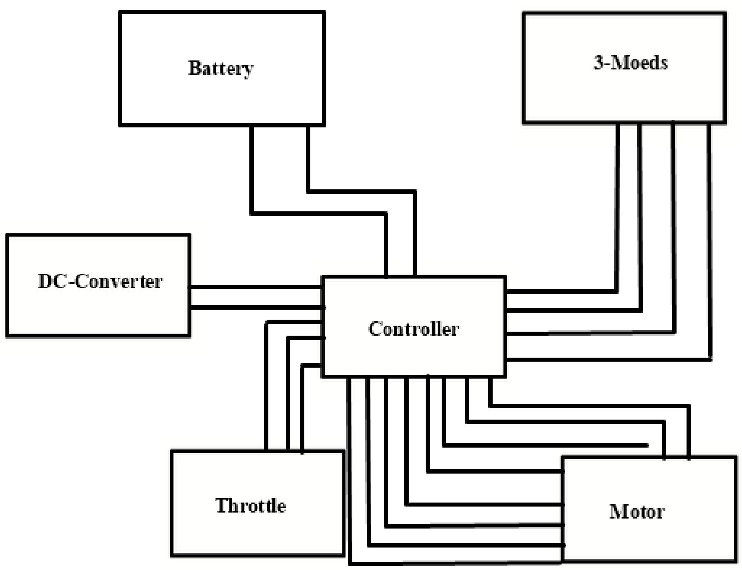

Figure 1 Schematic of the overall system circuitry

Figure 1 The CAD model of the hybrid motorbike

B. The design criteria

The design criteria for the fabrication of the hybrid motorbike are tabulated in Table 1.

Table 1 Key Criteria and Description

Key Criteria	Description
Functional	The capacity of the motorcycle and each of its systems to work together in perfect harmony is referred to as the project's functionality. The motorbike must be able to move to utilize different energy sources. At any time or place that is convenient for the user, the bike should be able to recharge or refill.
Efficient	Comparisons to the bike's initial manufacturing version may be made, the efficiency should be provable.
Affordable	To reduce the overall investment, used, recovered, or fairly priced parts should be used whenever possible. The objective is to create a product that is accessible to everyone.
Available	The technology used must be widely accessible to the public. To meet deadlines for projects, it must be simple to achieve.
Sustainable	This project's overarching justification is sustainability. As a result, the project's many components ought to be as sustainable as possible. When possible, used, second-hand, and salvaged parts and components should be chosen and put to use. The project's end-of-life and decommissioning should allow for the future reusing or recycling of said components.

Street Legal	The motorcycle ought to operate and behave exactly like any other street motorbike. The bike should be able to abide by all guidelines established by regulating authorities to be more readily accepted on a large market basis.
Style/ Design	This standard speaks of the aesthetics, ease of use, texture, and sound that satisfy users' senses. The project's goal is to maintain the design and functions that motorbike lovers most adore to satisfy market demand.
Secure/ Durable	The motorbike must be reliable and secure. The motorbike's original structural integrity and load-bearing capacity need not be altered. None of the systems or technologies used should make riding a bike on the road inherently unsafe.
Universal	All technological advances and systems must be adaptable to various motorbike designs and other vehicle applications that the market requires. The idea ought to be universal so that it may be applied and duplicated elsewhere.

C. Parts and their description

The parts along with a description of the designed and fabricated hybrid motorbike are mentioned in Table 2.

Table 2 Parts along with description

Part	**Description**
Controller	The component that connects both the electrical and mechanical parts of the hybrid electric motorcycle.
BLDC Motor	Perform similarly to direct-drive hub motors, but the electric motor inside the hub rotates at a significantly faster speed.
Charger	Stores the energy, then transforms it using a converter into AC so that our hybrid electric motorcycle's charger can utilize it.
Lithium-ion battery	Predominantly used for pedicels and Electric Motor-bikes because they can store more power with their high energy density and relatively low weight
Throttle	Similar to a motorcycle or electric scooter, when it is engaged the motor provides power and propels the Electric Motor-bike forward
Tires	Mechanical Electric Motor-bike tires are made up of a rubber-impregnated textile casing, also known as the carcass, and extra rubber on the surface that meets the road, known as the tread.

Chains	Mechanical Electric Motor-bike chain is a roller chain that transmits power from the gears and motor to the drive wheels, propelling it forward.

D. Components used in fabrication

The structural core of a motorcycle is its **frame or chassis** shown in **Fig. 3**, which gives its numerous parts support, sturdiness, and rigidity. It acts as the base to which all other components are connected. A motorcycle's frame is made to support the weight of the vehicle, fit the engine and other mechanical parts, and give the rider stability and control. The motorcycle's headstock (where the front fork and handlebars are mounted) and the back are connected by a central framework known as the main frame. It often consists of steel, aluminum, or other lightweight tube or beam-like constructions. The motorcycle's primary frame determines the bike's overall geometry, size, and shape. frames are supplementary structural elements that are attached to the main frame on some motorcycles. The seat, the rear bodywork, and occasionally the rear suspension parts are supported by sub-frames. To facilitate maintenance and customization, sub-frames are frequently detachable or fastened on. Different types of frames are available for motorcycles, including the backbone frame (where the engine serves as a structural part), the trellis frame (characterized by open-lattice construction), the diamond frame (often used in conventional motorcycles), the perimeter frame (found in sport-bikes), and others. In terms of weight, strength, and flexibility, each style of frame offers distinctive qualities.

Figure 3 Frame or Chasis

The **battery pack** consists of 16 Li-ion 18650 cells (shown in **Fig.4**) that are connected in series and have a nominal voltage of 3.7V and a combined capacity of 10Ah. There are five groups of 16 cells connected in parallel since the pack is set up in a 5P (5 parallel) configuration. The individual cell voltage (3.7V) is multiplied by the quantity of series-connected cells to determine the nominal voltage of the battery pack. In this scenario, the battery pack's nominal voltage would be 3.7V x 16 = 59.2V, and the battery pack's capacity is estimated by dividing the number of parallel sets by the individual cell capacity (10Ah). In this scenario, the battery pack's total capacity would be 10Ah x 5 = 50Ah. To avoid overheating, voltage instability, and possible safety risks, the maximum charge and discharge currents must be followed. The charging and discharging circuits regulate the current within these constraints when developing a system that uses this battery pack.

Fig. 4 Li-Ion Battery Cell

Motor controller's matching input terminals are connected with the positive and negative terminals of the battery pack as depicted in **Fig.5**. The battery's power output to the BLDC motor is controlled by the motor controller.

Fig.5 Battery Connection with BLDC Motor

The selection of the battery is based on the composition, dimensions, mass, expenses, electricity, and volume. A common rechargeable battery type found in many gadgets, including laptops, torches, power tools, and electric cars, is the 18650 Li-ion battery. Regarding the charging of 18650 Li-ion batteries. for a hybrid motorcycle, a lithium-ion cell battery with a voltage of 60 volts and a current of 10 amps might be a good option. The hybrid motorbike's electric motor receives its principal power from the lithium-ion battery. The battery supplies enough power to run the motor and move the vehicle thanks to its high voltage and current capacity. Internal combustion engine (ICE) and battery work together to produce combined power. The electric motor, which helps the internal combustion engine (ICE) during acceleration, hill climbing, or other high-demand conditions, is powered by the battery and lessens the burden on the engine as a result. A battery's longevity, accessibility, and reliability are all directly impacted by its management. The "brains" of a battery configuration are typically integrated battery management systems (BMS), which control output, charging, and discharging, as well as security. Preventing harm to the batteries. If not charged correctly, Li-ion batteries can be highly brittle and even deadly. A cell's capacity can be permanently diminished if it is discharged below a predetermined threshold, but it can also get damaged if it is overcharged and causes overheating with the potential for flame or explosion. It is ideal to maintain the individual cells in a battery pack with many cells at the same state of charge (SOC). A cell in a pack can undermine the integrity of the entire pack if it drops below the lower threshold. By managing voltages, a correctly operating BMS keeps cells from being overcharged or drained to dangerous levels, improving the dependability of Li-ion batteries. After a few discharge cycles, some builders omit the BMS and manually balance the cells using individual chargers. I chose to wire a BMS system between the battery cells to increase safety, prevent harm to the batteries, and make the charging process simpler**.**

It is necessary to use a certain capacity of **charger** to safely recharge a lithium-ion battery. Many of these particular devices have been developed to automatically determine the battery type and chemistry and provide a safe charging current to the cell. Most lithium-ion batteries operate in the 2.5 V to 4.2 V range, where 2.5 V represents their maximum discharge state and 4.2 V is their maximum charge state. Although they use a different charging method, 18650 lithium-ion batteries have a nominal voltage of V, the same as regular AA and AAA alkaline batteries. The voltage of regular AA and AAA alkaline batteries is 1.5 V. Another essential feature of a dedicated lithium-ion charger is to stop the charge cycle when the battery reaches 4.2 V because overcharging an 18650 battery might lead to interior damage.

A **BLDC (Brushless DC)** motor with a power rating of 1500 watts is used for hybrid electric motorbike, depending on various factors such as the vehicle's weight, desired performance, and efficiency requirements. Since the position of the electric motor in the bike was essential to how it would ultimately look and, more crucially, function. The motors are mounted on the majority of motorcycles near the back of the swing arm where it attaches to the frame (usually referred known as the jackshaft) and serves as the suspension's pivot. When the motor is activated, the torque from it pulls on the chain and rear tire while causing the suspension and chain length to alter as little as possible. The chain is then connected by both the motor sprocket and the rear sprocket around the swing arm. Occupying any of the small engines by space, preventing other larger components from fitting within. Since the moving drive components of the bike would be installed as a single unit, mounting the motor in this location would also prevent the potential of un-sprung weight and the possibility of different chain lengths when the bike is powered. A motor mount steel structure was created and welded it to the swing arm after taking all the necessary measurements for clearance and chain length as shown in **Fig.6**. After that, the motor was fixed to the frame.

Fig.6 Motor mount built and installed

The shaft that drives the motor must be connected to the gear system's input shaft to connect a brushless DC (BLDC) motor to it. With this configuration, the motor may transfer rotational power to the gear system, which can subsequently change the motor output's torque and speed characteristics. BLDC motor was selected that satisfies our application's needs by taking torque, speed, voltage, and power rating into account. The motor and gear system are firmly mounted in a secure location as demonstrated in **Fig.7**..

Fig.7 BLDC Motor connection with gear system

The setup's stability and performance with the setup's weight, vibrations, and any other environmental conditions were checked and connected the BLDC motor's electrical lines to an appropriate motor controller or drive circuit as visualized in **Fig.8**. The motor controller provides the motor the required power and control signals.

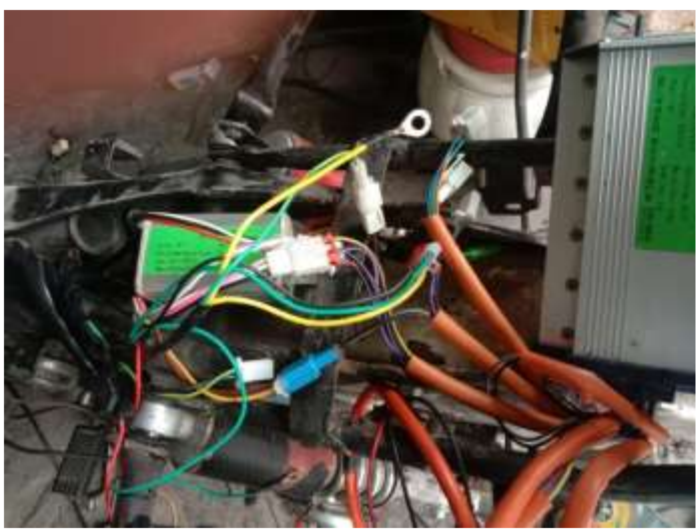

Fig.8 Wires connection with Motor

The **controller** is essential in directing the power flow between the BLDC (Brushless DC) motor and the rest of the system in a hybrid motorcycle. A BLDC motor that can deliver the speed, torque, and power your hybrid motorcycle needs. Voltage, current, power rating, and physical size are important considerations. BLDC motor controller was used that is appropriate for use with electric vehicle applications. Regenerative braking, speed control, and the correct power ratings for our motor should all be included in the controller. A hybrid motorcycle's battery pack serves as the power supply, therefore the motor controller was attached to it and shown in **Fig.9**. The battery pack's voltage and current requirements are regulated by the controller. Motorcycle's functionality was carefully checked after completing the connections.

Fig.9 Controller Connections

The **speedometer** shown in **Fig.10** on a hybrid motorbike connects to several sensors and devices to collect data and show the rider pertinent information. Although a speedometer's main function is to show the motorcycle's current speed, it often uses inputs from a variety of sources, including information on the wheel speed and the engine's rotational speed. The fact that a hybrid motorcycle's speedometer only displays voltage reveals that the device is intended to display data specific to the electrical system, most notably the battery voltage. Due to their combination of an internal combustion engine and an electric motor supplied by a battery, hybrid motorcycles may find usage for this feature. Battery voltage is an important parameter to monitor in a hybrid motorcycle as it can indicate the state of charge of the battery, which directly affects the available electric power and the overall performance of the electric motor. By displaying the voltage, the rider can have a quick visual reference to assess the battery's condition

Fig.10 Speedometer Showing Voltage of the Battery

Since **disc brakes** have better modulation than wheel brakes, the rider can more precisely measure the amount of clamping power produced. Peak braking power occurs just before lock-up, and bikes with disc brakes are better able to stay on the edge without going over. A disc brake is preferred over a wheel break for mechanical hybrid electric motorbikes. By altering the size of the rotors, we may increase (or decrease, depending on our preferences) the braking power of our mechanical hybrid electric motorbike. While a smaller rotor will save weight for riders who do not necessarily require the additional braking force, a larger one will boost mechanical leverage and heat dissipation. Just doesn't require the additional braking power. Disc brake systems have far higher stopping power than the wheel and other brake systems, which means that less force at the lever is needed to produce the same degree of deceleration as on a wheel brake or other breaking system. The mechanical disc brake for an electric motorbike is depicted in the **Fig.11**.

Fig.11 Disc brake System

E. Connections of different components

The overall connections between the various parts of a hybrid motorcycle, which could consist of a 1500-watt BLDC motor, a 60-volt 10-ampere battery, a controller, and a speedometer are depicted in **Fig.12**. The controller is connected to the battery, which has a rating of 60 volts and 10 amps. The battery's positive terminal is connected to the controller's positive input, while its negative terminal is connected to the controller's negative input. The controller is powered via this connection to enable operation. The controller controls the battery's and the motor's power flow. To manage the motor's speed and torque, it modifies the voltage and current. The specifications of the controller and motor determine the precise connections between them. A hybrid motorcycle's speedometer might not be connected to the controller directly. Instead, it might get speed data from other sensors or motorcycle systems. Usually, the wheel speed sensors, which detect the rotation of the wheels, provide speed data to the speedometer. The motorcycle's electronic control unit (ECU) or instrument cluster receives data from these sensors and transmits it to the speedometer for display. But in our case, the speedometer is just connected to the battery only and shows only the voltage level of the battery.

Fig.12 Overall connections in a hybrid motorbike

III. Experimental conditions and results

A. Environmental conditions

The environment, location, and technologies used during the motorbike's road testing had to meet certain requirements to produce results. The area needed to be remote and isolated to prevent any disruption or interference from things like traffic or pedestrians as shown in **Fig.13**. To get the bike up to speed, sustain speed, and have a noticeable length of sight for safety, the road itself needs to generally have smooth pavement, straight and flat with little to no slope or curves, and several km long. The bike was tested over several days in the same experimental conditions as environmental factors significantly affected the results. The wind speed range of 9-15 km/h could add resistance and rain, or condensation on the road would influence adhesion and traction, while low temperatures (below 30 ^{o}C), would impact the amount of energy and power the Li-ion battery could provide**.** No major modifications or adjustments that would materially influence the weight or performance of the motorcycle would be made in between testing days. With an overall mass of 180 kg and sporting the exact gear. The clothing included a full-face helmet, a mesh jacket made of textile, leather leg boots, mesh gloves, and trousers.

Fig.13 Jalozai campus as a testing site for the hybrid motorbike

B. Design calculations

Weight of the Battery plus Controller Mass = 6.5kg

BLDC Motor Mass= 5.5kg

Tire plus frame= 35kg

Normal person weight = 70kg

The factor of safety= 1.5

Total mass = 180kg

Total weight = 1764N

Radius of tire = 0.3045 m

The normal reaction of each tire = 1764/2

F_n = 882N

$$\text{Friction force on each tire} = F_f = \mu * Fn \quad (1)$$

$$\text{Torque} = T = F_f * r \quad (2)$$

$$\text{Angular speed} = w = v/r \quad (3)$$

$$\text{Power required for Plane Road} = P = T * w \quad (4)$$

Power required for Inclination:

$$F = \mu mg \cos\theta + mg \sin\theta \quad (5)$$

$$\text{Input power} = F.V \quad (6)$$

$$\text{Output Power} = \text{Torque} \times \text{Angular Velocity} \quad (7)$$

$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \times 100 \quad (8)$$

The various calculated quantities and parameters are listed in **Table 3** and **Table 4**.

Table 3 Design parameters for the hybrid motorbike

Speed (km/h)	Weight (N)	Radius (m)	Angular Velocity (rad/s)	Friction Coefficient	Friction Force	Torque (Nm)	Power (W)	Output Power (W)	Efficiency (%)
15	1764	0.3048	13.67	0.03	26.46	8.065	220.66	109.98	0.416
20	1764	0.3048	18.22	0.03	26.46	8.065	293.89	219.94	0.415
25	1764	0.3048	22.78	0.03	26.46	8.065	367.50	292.98	0.415
30	1764	0.3048	27.34	0.03	26.46	8.065	440.99	403.69	0.416
35	1764	0.3048	31.89	0.03	26.46	8.065	514.50	473.35	0.416

Table 4 Design parameters for the hybrid motorbike

Speed (km/h)	Weight (N)	Radius (m)	Angular Velocity (rad/s)	Friction Coefficient	Friction Force	Torque (Nm)	Input Power (W)	Output Power (W)	Efficiency (%)
15	1565	0.3048	13.67	0.03	20.66	8.065	264.60	105.77	0.399
30	1565	0.3048	18.22	0.03	20.66	8.065	352.80	146.49	0.415
40	1565	0.3048	22.78	0.03	20.66	8.065	441.00	182.96	0.415
55	1565	0.3048	27.34	0.03	20.66	8.065	529.20	219.94	0.415
65	1565	0.3048	31.89	0.03	20.66	8.065	617.40	256.42	0.416

C. Cost breakdown

The details of the components and parts purchased for the fabrication along with their prices are given in **Table 5**.

Table 5 The cost of the purchased components

Components	Cost in PKR
BLDC Hub motor (1500W)	40000
Li-Ion Battery (60V 10Ah)	38000
Li-Ion Battery charger	7000
Controller	13000
DC-DC Converter	9000
Miscellaneous (wires, connectors, etc.)	6000
Labor	27000
Bike	24000
BLDC Motor driver	6000
Total Cost	170000

D. Assessment Test 1

27°C, Clean, Pleasant, and with a 13km/h light breeze from the Northeast (not felt on the forehead or body). Trailed the bike to the testing location with a fully charged battery for Day 1 of the testing. Since this would be our first time using the bike, I wanted to make sure it was stable, completely working properly, and operationally safe. We started cautiously and checked the starting system, lights, horn, speedometer, brakes, and accelerator. Once the bike has been stopped and checked for shortcomings, wear, or damage, the acceleration, top speed, cruising speed, and range are tested. Although after analyzing the data, there was little indication of any significant change, we tested the bike in both directions to account for any tiny slopes in the road or wind. We would hit the brakes anytime we were slowing down and stop as soon as we could to avoid affecting the results. The motorcycle operated nicely. The motorcycle traveled a total of 25.5 km before cutting off the motor's power (a safety device to prevent damage from over-discharge); its peak speed was recorded at 65.3 km/h, its average speed was 48.19 km/h, and the total amount of energy it used was 1565 Wh. The motor required 2768W of power and used 65.3 Wh/km while running at full throttle and traveling at 65.3 km/h. Despite being pleased with these outcomes, we fell short of the target speed of 80 km/h, which is the legal highway limit. The relationship of speed with input power and efficiency during test 1 are depicted in **Fig.14** and **Fig.15** respectively.

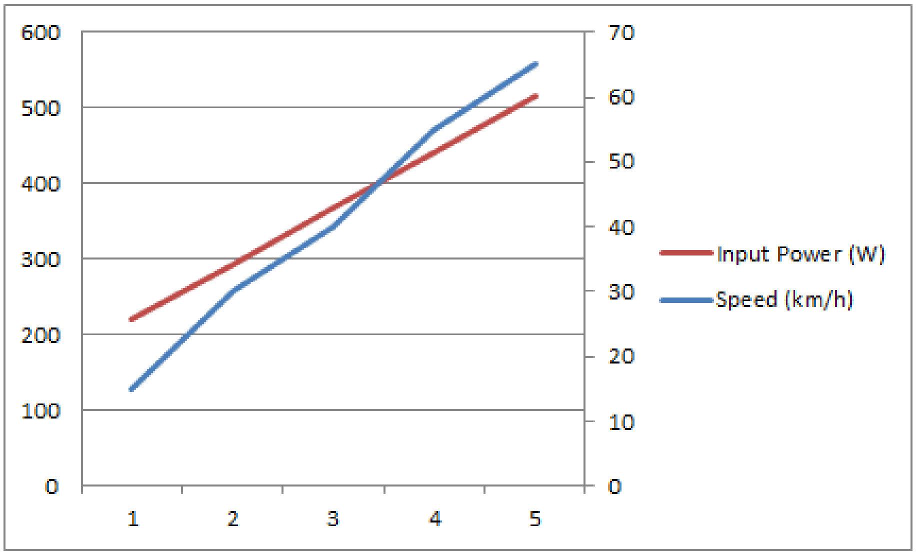

Fig.14 The relationship of speed with input power during test 1

There appeared to be a plateau in efficiency, particularly noticeable between speeds of 15 km/h to 40 km/h. This plateau indicates that speed changes have minimal impact on efficiency within this speed range. While the efficiency remains relatively stable, there were slight variations in efficiency across different speeds. These variations may be attributed to factors such as variations in friction, aerodynamics, and other operational conditions. The highest efficiency was achieved at a speed of 55 km/h and 65 km/h, where the efficiency reached approximately 41.6%. This suggests that the motorbike system is optimized for efficiency within this speed range.

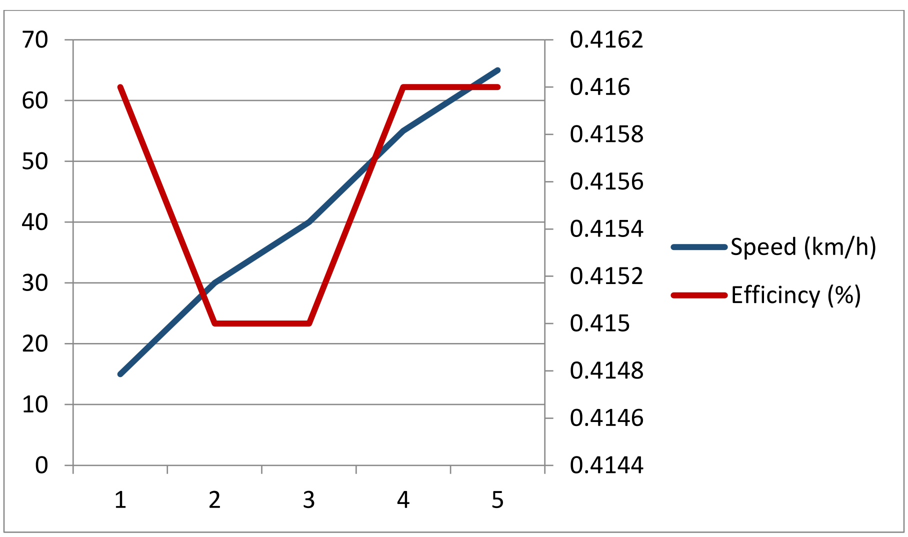

Fig.15 The relationship of speed with efficiency during test 1

E. Assessment Test 2

Environmental Conditions: 23°C, clean, with a sun-cloud mix, and a light breeze from the northeast at 9.5 km/h (not felt on the forehead or body).

The motorcycle reached a high speed of 65 km/h on the second day of testing under very comparable climatic conditions (9.5 km/h wind, 23 degrees Celsius). It covered a distance of 24.37 km overall, moving at a speed of 42.35 km/h. The motor required 617.40W to sustain 67km/h when its weight was changed from 1764N to 1665N. The graphs for speed vs input power and efficiency for test 2 are shown in **Fig.16** and **Fig.17** respectively.

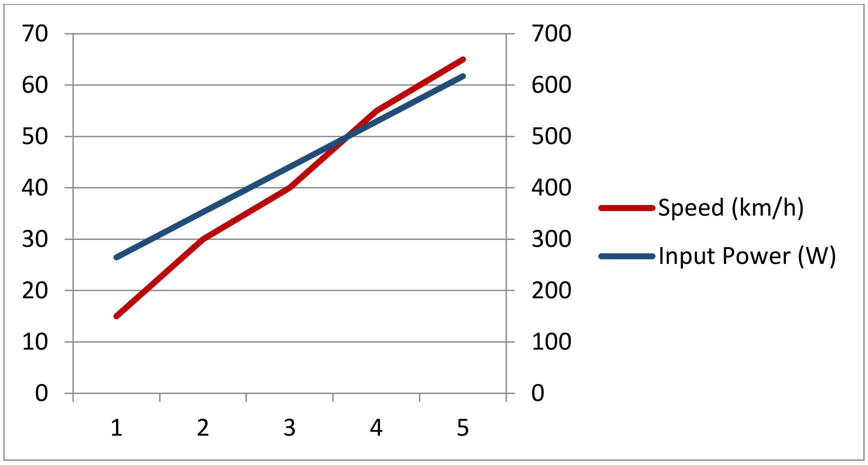

Fig.16 Speed vs input power for test 2

From 30 km/h to 55 km/h, the efficiency remains relatively consistent, hovering around 41.5%. This suggests that within this range, speed changes don't significantly impact efficiency. At higher speeds (above 55 km/h), there was still a slight increase in efficiency. The efficiency was increased from 41.5% at 55 km/h to 41.6% at 65 km/h when weight was reduced fron 1764N to 1665N. The efficiency of a vehicle or system can be influenced by various factors such as aerodynamics, engine performance, road conditions, and driving habits.

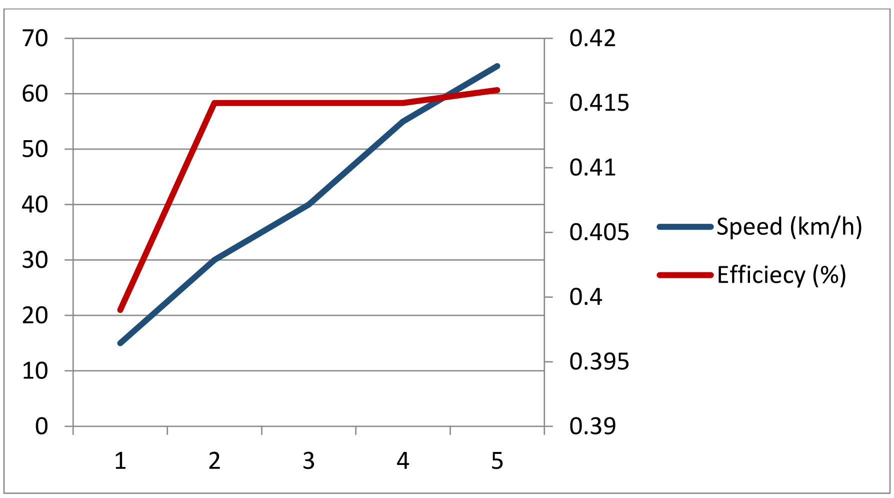

Fig.17 Speed vs Efficiency for test 2

F. Basic safety precautions

A hybrid motorcycle's performance, effectiveness, and general functionality are all evaluated during testing. The motorcycle's capacity is checked to quickly and smoothly accelerate from a stop or during overtaking. Identify the top speed the motorcycle can reach under typical operating circumstances. Examine the hybrid system switches between combustion and electric power sources to make the transition smooth and responsive. Calculate how far the motorbike can go on electric power alone before the battery needs to be recharged. Analyze the torque, responsiveness, and efficiency of the electric motor when it is operating solely on electricity. Check whether the regenerative braking technology recharges the battery effectively when the vehicle is decelerating. Applying the proper charging infrastructure, calculate the amount of time needed to fully recharge the battery from a dead state. Examine the battery management system's correctness and dependability in delivering data on the battery's status, including temperature, voltage, and charge level. Analyze the braking system's performance and reactivity, taking into account both mechanical and regenerative braking. Be sure to evaluate the motorcycle's stability, cornering ability, and general handling qualities.

IV. Conclusions

Hybrid motorcycles stand for a potential and cutting-edge mobility alternative. These motorcycles offer better fuel efficiency, lower emissions, and a longer range than standard motorcycles because they combine the advantages of electric and internal combustion engine technologies. In the current study, the results of an initial study into the fuel effectiveness of a hybrid electric motorcycle are given. The following conclusions could be drawn for the designed and fabricated hybrid motorbike:

- The hybrid motorcycles have the ability to switch between electric power and gasoline power, providing flexibility to riders. They offer a transition option for riders who are not yet ready to fully commit to electric motorcycles due to concerns about range limitations and charging infrastructure.
- Electric mode allows for zero-emission riding, making it an environmentally friendly choice for short commutes and urban areas, where emissions and noise pollution are major concerns. On the other hand, the internal combustion engine provides extended range and higher power output for longer journeys or situations where quick acceleration and higher speeds are required.
- The integration of regenerative braking technology in hybrid electric motorcycles is another significant advantage. When braking or decelerating, the electric motor acts as a generator, converting the kinetic energy into electrical energy, which is then stored in the battery. This regenerative braking system increases energy efficiency and helps to extend the overall range of the motorcycle.
- This hybrid electric motorcycle contributes to reducing overall carbon emissions and dependence on fossil fuels, especially if the electricity used for charging the battery comes from renewable sources.

Conflicts of interest

The authors declare that they have no affiliations with or involvement in any organization with any financial or non-financial interest in the subject matter and materials discussed in this article.

Ethical Approval

Not Applicable

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