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Design and Fabrication of Hybrid E -Vehicle Two-Wheeler

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Abstract

The increasing demand for sustainable transportation has led to the development of Hybrid Electric Vehicles (HEVs). This project focuses on the design and fabrication of a Hybrid E-Vehicle Two-Wheeler, integrating an Internal Combustion Engine (ICE) and an electric motor to enhance efficiency, sustainability and reduced emissions. The design phase involves selecting optimal components, including an electric motor, IC Engine, lithium-ion battery and control system, ensuring seamless performance. A parallel hybrid system is adopted for smooth power source switching, optimizing fuel consumption and reducing emissions. The fabrication process reimagines the chassis to accommodate both powertrains while maintaining structural integrity and weight distribution. A bicycle frame is used to integrate the IC engine and PMDC motor efficiently, followed by assembling key components, wiring the electrical system and adding essential features like braking and lighting systems. The project aims to demonstrate the feasibility of hybrid two-wheelers by assessing their performance under various operating conditions, contributing to advancements in hybrid vehicle technology and promoting eco-friendly transportation alternatives.

Keywords: Bicycle Chassis, IC Engine, PMDC Motor, Lithium-Ion Battery, Parallel Hybrid, Eco-Friendly Mobility.

I. INTRODUCTION

In recent years, the demand for environment friendly transportation alternatives has grown significantly. As concerns about air pollution, rising fuel prices and the depletion of fossil fuels continues to intensify the need for sustainable and energy-efficient vehicles has never been more pressing. While Electric Vehicles (EVs) are gaining popularity, they often come with limitations such as limited range and long charging times. On the other hand, traditional Internal Combustion Engine (ICE) vehicles contribute to air pollution and high fuel consumption. A viable solution to address these challenges is the development of Hybrid Electric Vehicles (HEVs), which combine the benefits of both electric motors and ICE.[2]

II.SYSTEM STUDY

A. EXISTING SYSTEM

The current system primarily consists of conventional Electric Vehicles (EVs) that rely solely on battery power or traditional vehicle with internal combustion engines (ICEs) that lack hybrid integration. Electric Vehicles (EVs) provide a clean and efficient mode of transportation but suffer from range limitations due to battery dependence, while IC Engine based vehicle contribute to fuel consumption and emissions.[6]

B. DISADVANTAGES OF EXISTING SYSTEM

- Limited range due to complete dependence on a single power source.
- Higher fuel consumption in ICE-based bicycles.
- No energy optimization using hybrid technology.
- Environmental concerns due to emissions from fuel-powered systems.

C.PROPOSED SYSTEM

The proposed Hybrid E-Vehicle Two-Wheeler addresses the limitations of traditional systems. It incorporates:

1. Integration of both ICE and electric motor in a bicycle chassis for hybrid operation.
2. Use of a lightweight lithium-ion battery for improved efficiency.
3. Design of a compact, lightweight frame ensuring proper weight distribution.
4. Implementation of eco-friendly and energy-efficient hybrid technology.

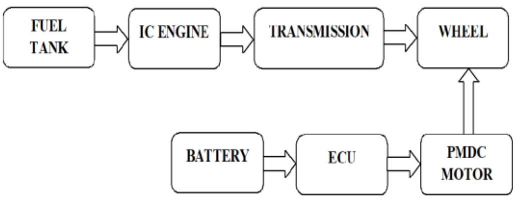

Fig.1. Represent the block diagram of the proposed system.

D.ADVANTAGES OF PROPOSED SYSTEM

- Improved Fuel Efficiency: The hybrid system optimizes power usage by switching between the electric motor and ICE, reducing overall fuel consumption.
- Extended Range: Unlike fully electric bicycles, the hybrid model eliminates range anxiety by utilizing an ICE for longer-distance travel when the battery is low.
- Lower Emissions: By incorporating electric propulsion, the system significantly reduces carbon emissions compared to conventional fuel-powered two-wheelers.[7]
- Cost-Effective Operation: Reduced fuel dependency and efficient energy utilization lower operational costs, making it a more economical alternative
- Increased Reliability: The hybrid system provides backup power through the ICE, ensuring continuous operation even if the battery depletes.

III.DESIGNING CALCULATIONS

A. VEHICLE CALCULATION:

1.Total weight calculation:

Table 1. Total weight calculation

Component	Weight (kg)
Chassis	10
Battery	1.3
Motor (PMDC)	1.5
Engine (50cc ICE)	10
Fuel tank (2.5L Petrol)	2.3
Rider	60
Total Weight (W)	85.1 kg

$$Weight\ force(W) = mg \quad \text{-------} \quad (1)$$

m = Mass of the vehicle

g = Acceleration due to gravity(9.81m/s²)

$$W = mg$$
$$= 85.1 \times 9.81$$
$$Weight\ force(W) = 834.831N$$

2.Rolling resistance force:

The rolling resistance force (Fr) occurs due to the friction between the tires and the driving surface. The rolling resistance force is zero at standstill. When the vehicle starts moving, the rolling resistance force acts in the direction opposite to the direction of motion.

$$\mathrm{Fr} = \mathrm{CrMg} \quad \text{-------} \quad (2)$$

where,

Cr = Rolling resistance coefficient (0.015)

M = Mass of the vehicle

g = acceleration due to gravity(9.81 m/s²)

$$Fr = 0.015 \times 85.1 \times 9.81$$
$$Fr = 12.5N$$

3. Aerodynamic drag force:

As the vehicle speed increases, the aerodynamic drag force (Fd) opposes the vehicle motion as the air as is forced to flow around the moving vehicle. It is hence important to note that the aerodynamic drag in independent of vehicle mass but has a strong dependence on the vehicle speed.[3]

$$Fd = ½\ CdA\ \rho\ v2 \ \text{-------} \quad (3)$$

Where,

Cd = drag coefficient (0.9 for motorcycles)

A = frontal area of the vehicle (0.5 m² estimated frontal area)

ρ = density of the air (1.225 kg/m³ air density)
v = velocity of the vehicle (45 km/h = 12.5 m/s)

$$Fd = 21 \times 0.9 \times 0.5 \times 1.225 \times (12.5)2$$

$$Fd = 43.06N$$

4. Gradient force:

The third force that acts on a vehicle is the gradient force, and it occurs when the vehicle is driving on an uphill or a downhill road. The gradient force is due to the longitudinal component of gravitational force, namely mg where theta is the inclination angle of the road. Gradient force force (Fg) is,

$$Fg = mg \sin\theta \qquad \text{-------} \ (4)$$

Where,
m = Mass of the vehicle
g = Acceleration due to gravity(9.81m/s²)
θ = 10° (good middle-ground to evaluate real-world climbing performance)

$$Fg = 85.1 \times 9.81 \times sin(10)$$

$$Fr = 144.9N$$

5. Net force on the vehicle:

The net force on the vehicle is the sum of all resistive forces that the motor and engine must overcome.

$$Fnet = Fr + Fd + Fg \qquad \text{-------} \ (5)$$

$$= 12.5 + 43.06 + 144.9$$

$$Fnet = 200.46N$$

The above calculations state the amount of net force that the vehicle should overcome.

B. MOTOR CALCULATION:

Table 2. Comparison of Motor Types

Motor Types	Advantages	Disadvantages
PMDC Motor	High starting torque, simple control, low cost, compact size	Requires periodic maintenance due to brushes
BLDC Motor	High efficiency, long lifespan, low maintenance	Requires complex electronic controller, higher initial cost
Induction Motor	Robust and reliable, low maintenance	Lower starting torque, requires inverter for control
Stepper Motor	High precision and control	Not suitable for high-speed applications
Servo Motor	Precise speed and position control	Expensive and requires feedback control system

Table 3. PMDC Motor Specifications

Rated voltage	24V
Rated speed	3000RPM
Output power	250W
Current	13.4A
Insulation class	E
Brand	Alter
Reduction ratio	9:6
Material	Aluminium

From the specification,

$Maximum\ current, Imax = P/V$ ------- (6)

= 250/24

Imax = 10.41A (at its full load condition)

C. MOTOR GEAR REDUCTION CALCULATION:

A gear reduction system is an essential component in an electric vehicle (EV) drivetrain, allowing the motor to deliver higher torque while reducing the output speed.

a) Importance of Gear Reduction:

- Increases Torque: Reduces speed while increasing torque for better vehicle traction.
- Optimizes Motor Performance: Allows the motor to operate at an optimal speed range.
- Enhances Efficiency: Reduces stress on the motor, leading to lower power consumption.
- Provides Smooth Acceleration: Ensures a controlled power delivery to the wheels.

b) Reduction Ratio:

The reduction ratio (also called the gear ratio) is the ratio of the motor’s rotational speed (input speed) to the speed of the driven shaft (output speed). It is expressed as,

Reduction ratio = Input speed (N1) / Output speed (N2) ----- (7)

For PMDC Motor, Rated speed (N1) = 3000 RPM

Reduction ratio = 9:6

The output speed after gear reduction is (N2) = 3000 / 9/6

= 3000 x 6 / 9

= 2000 RPM

So, the final output speed after reduction is 2000 RPM.

D. MOTOR TORQUE CALCULATIONS:

When selecting a motor for a hybrid EV, it is important to determine the output torque at the wheels. This is influenced by the motor torque and the gear reduction ratio.[4]

From the PMDC motor**,** we have:

Motor Power = 250W
Rated Speed of Motor (N) = 3000 RPM
Reduction Ratio (RRR) = 9:6 (or 1.5:1)
Gearbox Efficiency (η) = 90% (0.9)

$$T = \omega / P \qquad \text{-------} \quad (8)$$

Where,

P = Power in Watts
ω = Angular speed in radians per second

First, convert RPM to angular speed:

$$\omega\ \text{Motor} = 2\pi \times 60N \qquad \text{-------} \quad (9)$$

$$\omega\ \text{motor} = 2\pi \times 60 \times 3000$$

$$= 314.16\ \text{rad/s}$$

Now, calculate motor torque:

$$T\ motor\ = \ 250/314.16$$

$$= 0.796\ \text{Nm}$$

Apply gear reduction,

$$Tout = T\ motor \times R\ \times \eta \qquad \text{-------} \quad (10)$$

$$T_{out} = 0.796 \times 1.5 \times 0.9$$

$$T_{out} = 1.07\ \text{Nm}$$

Thus, the output torque of the vehicle is 1.07 Nm.

E. BATTERY CALCULATION:

Table 4. Battery specification

Battery specification	
Battery type	Lithium-ion
Rated voltage	24V
Rated current	12Ah

a) Discharging rate:

From the motor the load current = 10.41A

Battery capacity = 12Ah

Battery discharging rate = Battery capacity / load current ------- (11)

= 12Ah / 10.41 A

= 1.15hrs

If the battery is fully charged, it will deliver power for 1.15hrs with the load current of 10.41A.

b) Charging rate:

Battery capacity = 12Ah

Input current from (battery charger) = 3A

= 12 Ah / 3A

Charging rate = 4hrs

If the battery is fully discharged, it will take 4hrs to recharge it again.

IV.HARDWARE DESCRIPTION

a) LITHIUM-ION BATTERY (24V,12AH):

Fig.2. Lithium-ion Battery(24V,12Ah)

A 24V, 12Ah rechargeable Lithium-ion battery pack (7S configuration with 28 cells in series-parallel) is designed to provide a stable and efficient power supply for hybrid electric vehicles(HEV), E-bikes. The battery pack consists of 28 individual lithium-ion cells, which are arranged in a 7S4P configuration meaning there are 7 cells connected in series (7S) and 4 parallel groups (4P) to achieve the required voltage and capacity. Each lithium-ion cell typically has a nominal voltage of 3.7V and a capacity of 3Ah, so when 7 cells are connected in series, the total voltage of the pack becomes 7 × 3.7V = 25.9V (nominal), and when fully charged, it reaches 4.2V × 7 = 29.4V. The parallel configuration (4P) increases the overall capacity by summing the individual capacities of each parallel group, resulting in 3Ah × 4 = 12Ah, which determines how long the battery can supply power before requiring a recharge.[5]

Internally, the Battery Management System (BMS) plays a crucial role in monitoring and controlling the battery's operation, ensuring cell balancing, overcharge protection, over-discharge protection, short circuit protection, and thermal management. Since lithium-ion cells are sensitive to voltage fluctuations and excessive charging or discharging, the BMS equalizes the charge among all the cells to prevent imbalances that could lead to overheating, reduced lifespan, or even thermal runaway. During charging, an external lithium-ion charger applies a Constant Current (CC) and Constant Voltage (CV) charging profile, where the battery initially charges at a constant current until it reaches its peak voltage of 29.4V, after which the charger switches to constant voltage mode, gradually reducing the current until the battery reaches full charge[9]. During discharge, the battery supplies power to the load (i.e., an electric motor) by delivering a steady DC voltage and current, regulated by the BMS to prevent deep discharge, which could damage the lithium cells.[8]The battery's energy is released through a chemical reaction between the cathode and the anode (typically graphite), allowing lithium ions to move through an electrolyte during discharge and reversing this process during charging. This efficient energy conversion, lightweight design, high energy density, and long cycle life make the 24V, 12Ah Lithium-ion battery an ideal choice for electric vehicle applications, offering reliable performance with minimal maintenance requirements.

b) ELECTRONIC CONTROLLER UNIT (ECU):

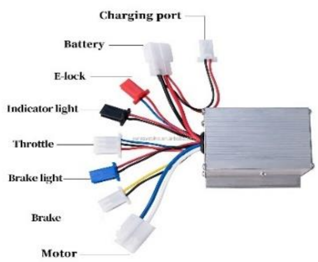

Fig.3. Electronic Controller Unit

The Electronic Control Unit (ECU) in a 24V electric vehicle system is responsible for managing power flow from the 24V, 12Ah Lithium-ion battery to the 24V Permanent Magnet DC (PMDC) motor, ensuring smooth and efficient operation. When the system is powered on using the E-lock (electric lock switch), the ECU activates and begins processing inputs from the throttle and brake systems. The throttle input, which typically varies between 0-5V, is interpreted by the ECU to adjust the motor's speed using Pulse Width Modulation (PWM), regulating the power supplied to the motor. As the throttle increases, the ECU increases the duty cycle of the PWM signal, allowing more voltage and current to flow to the motor, thereby increasing its speed[10]. Conversely, when the throttle is reduced, the ECU decreases the duty cycle, lowering the motor speed. When the brake is applied, the ECU instantly cuts power to the motor, ensuring immediate stopping of the vehicle. However, since this ECU does not support regenerative braking, the kinetic energy of the vehicle is dissipated as heat instead of being converted back into battery charge.[1]

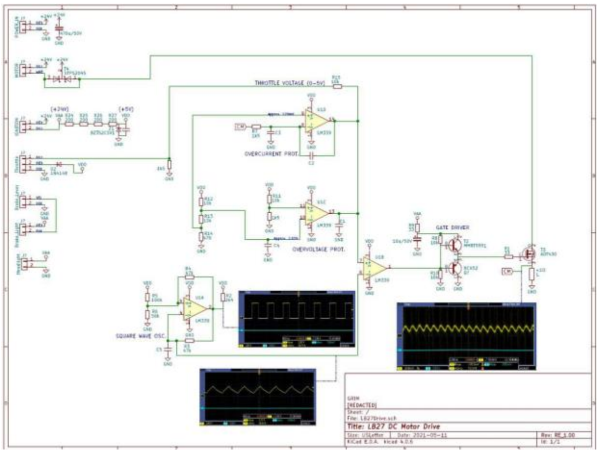

Fig.4. Circuit diagram of Electronic Controller Unit

c) PMDC MOTOR:

Fig.5. PMDC Motor

The Permanent Magnet DC (PMDC) motor is operated on a 24V DC supply and is rated at 250W output power, making it an essential component in the vehicle's propulsion system. The motor works on the principle of electromagnetic interaction between the permanent magnets in the stator and the current-carrying armature winding. When the Electronic Control Unit (ECU) supplies power to the motor, current flows through the armature windings, creating a magnetic field around them. This field interacts with the fixed magnetic field of the permanent magnets, generating a force that causes the armature to rotate. The rotation of the armature produces mechanical torque, which is transmitted to the wheels via a gear reduction system (9:6 ratio). The gear reduction system plays a crucial role in adjusting the high-speed rotation of the motor (3000 RPM) to a lower, more practical output speed while simultaneously increasing torque. This ensures efficient power delivery to the wheels, improving the vehicle's acceleration and ability to handle varying terrains.

Since PMDC motors do not require an external field winding (as seen in separately excited DC motors), they offer higher efficiency, compact size, and reduced energy losses. The motor draws 13.4A of rated current, ensuring adequate torque and speed control under normal operating conditions. In this system, the throttle input (0-5V signal) from the user controls the ECU, which regulates the motor speed using Pulse Width Modulation (PWM) to vary the power supply. When the throttle is increased, the ECU supplies more power, resulting in higher speed and torque. Conversely, reducing the throttle decreases power, slowing down the motor. The braking system works by cutting off power to the motor, bringing the vehicle to a stop. However, since this system does not implement regenerative braking, the kinetic energy of the vehicle is lost as heat instead of being converted back into electrical energy.

The insulation class E of the motor ensures that it can withstand higher temperatures and operate safely under prolonged usage conditions without electrical failures. The motor is also equipped with overcurrent protection via the ECU, preventing excessive power draw that could damage internal components. Due to its rugged design, high efficiency, and direct torque output, this PMDC motor is ideal for lightweight electric vehicles, e-bikes, and scooters, providing smooth acceleration, reliable operation, and efficient energy conversion for a sustainable and eco-friendly transportation solution.

d) INTERNAL COMBUSTION ENGINE (ICE):

Fig.6. Internal Combustion Engine (ICE)

A 2-stroke 50cc internal combustion (IC) engine operates through two distinct strokes: the compression stroke and the power (expansion) stroke, completing a full cycle in just one revolution of the crankshaft**.** The process begins with the intake and compression stroke**,** where the piston moves upward, compressing the fuel-air mixture inside the combustion chamber while simultaneously creating a vacuum in the crankcase, drawing in a fresh charge of air-fuel mixture through the intake port. As the piston reaches top dead center (TDC)**,** the spark plug ignites the compressed mixture, causing a rapid expansion of gases that forces the piston downward. This is the power stroke, generating the force needed to turn the crankshaft and propel the vehicle. As the piston descends, it uncovers the exhaust port, allowing burnt gases to exit the cylinder, while the fresh charge in the crankcase is pressurized and transferred into the combustion chamber through the transfer port. This simultaneous process ensures continuous power generation with each revolution, making 2-stroke engines highly efficient in delivering power for their size. An Internal Combustion Engine (ICE) comprises several interconnected systems including fuel system, air intake, exhaust system and starting coil.

Fuel tank:

Fig.7. Fuel Tank

Fuel tank is used to store and supply fuel for the 2-stroke internal combustion engine. This fuel tank is made of lightweight metal, designed to be durable and resistant to fuel corrosion. The fuel cap on top ensures a sealed environment, preventing fuel evaporation and contamination while allowing controlled ventilation to avoid vacuum formation inside the tank. Fuel flows from the tank to the carburetor through a fuel line, regulated by a petcock valve, which allows the rider to start, stop, or switch to a reserve fuel supply. The capacity of the tank is 2.5L.

Carburettor:

Fig.8. Carburettor

A carburettor is a crucial component in a 2-stroke internal combustion engine, responsible for mixing air and fuel in the correct ratio before delivering it to the engine's combustion chamber. It operates based on the Venturi effect, where air flows through a narrow passage, creating a low-pressure zone that draws fuel from the float chamber through a jet. The throttle valve controls the amount of air entering the carburetor, regulating engine speed and power output. A needle jet and main jet fine-tune the fuel flow, ensuring an optimal air-fuel mixture for different speeds and loads. The choke valve helps in cold starts by enriching the mixture with more fuel. The float and float valve maintain a steady fuel level inside the chamber, preventing overflow or starvation. As the mixture enters the engine, it is atomized and vaporized for efficient combustion, providing smooth acceleration and power delivery. Proper tuning of the carburetor is essential for fuel efficiency, performance, and emissions control.

Air intake:

Fig.9. Air intake

The air intake system in this setup plays a crucial role in supplying clean, filtered air to the engine for efficient combustion. The primary component visible in the image is the air filter, which is designed to remove dust, dirt, and other impurities from the incoming air before it enters the carburetor. The filter material, typically foam or paper, ensures that only clean air reaches the engine, preventing damage to internal components and improving fuel efficiency.
When the engine operates, the downward movement of the piston creates a vacuum that draws air through the filter and into the carburetor, where it mixes with fuel in the correct ratio. This air-fuel mixture is then delivered to the combustion chamber for ignition. A well-functioning air intake system ensures optimal engine performance by maintaining proper airflow, reducing contaminants, and preventing clogging in the carburetor. Regular maintenance, such as cleaning or replacing the filter, is essential to prevent restricted airflow, which could lead to reduced power output, poor fuel efficiency, and excessive engine wear.

Exhaust system:
The exhaust system plays a crucial role in expelling burnt gases from the engine after combustion while also improving engine efficiency and reducing noise. The visible exhaust pipe is connected to the engine's exhaust port and extends towards the rear of the vehicle. In a two-stroke engine, the exhaust system is designed to enhance scavenging, which is the process of efficiently clearing exhaust gases while drawing in a fresh air-fuel mixture. The expansion chamber, commonly found in such setups, helps in tuning the exhaust pulses to optimize power output by creating back pressure, preventing unburned fuel from escaping, and improving overall combustion efficiency. The muffler at the end of the exhaust system helps to reduce noise levels by dampening high-pressure sound waves.

Fig.10. Exhaust system

Starting coil:

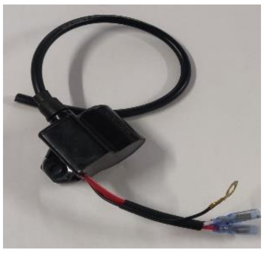

Fig.11. Starting coil

The starting coil, commonly referred to as the ignition coil, is a critical component in the ignition system of this engine. It is responsible for transforming the low-voltage electrical energy from the magneto into a high-voltage spark required to ignite the air-fuel mixture in the combustion chamber. The coil operates on the principle of electromagnetic induction and consists of primary and secondary windings. When the engine's flywheel rotates, the magneto generates an alternating current, which is fed into the primary winding of the coil. This rapidly builds up a magnetic field, which collapses when the contact breaker or electronic ignition system interrupts the circuit. The collapsing magnetic field induces a high-voltage current in the secondary winding, which is then sent to the spark plug via the high-tension cable. This high-voltage discharge at the spark plug produces a spark, igniting the compressed air-fuel mixture inside the cylinder. Proper functioning of the ignition coil ensures reliable engine starting, smooth operation, and optimal combustion efficiency.

e) THUMP THROTTLE CONTROL:

Fig.12. Thump throttle control

The thumb throttle is used as an engine accelerator, allowing precise control over the engine's power output. Unlike a twist throttle, this thumb-operated lever is designed for ease of use and ergonomic comfort, especially in setups where a traditional grip throttle might not be practical. When the rider presses the lever, it activates a mechanical or electronic linkage that modulates the engine's throttle position, adjusting the fuel or air intake accordingly. In internal combustion (IC) engine applications, the thumb throttle is typically connected to the carburetor or throttle body via a cable mechanism, pulling the throttle valve open to increase fuel flow and power output.

f) TRANSMISSION SYSTEM:

Electrical transmission:

Fig.13. Electrical transmission

In this transmission system, it transfers mechanical power from the 24V PMDC motor to the rear wheel using a chain drive mechanism. The motor, which generates rotational motion through electromagnetic interaction, is connected to a sprocket (small gear) mounted on the motor shaft. As the motor rotates, the sprocket drives the chain, which in turn rotates a larger sprocket attached to the rear wheel. This setup effectively transmits torque and motion, propelling the vehicle forward. The gear reduction system inside the motor housing (9:6 ratio) reduces the high-speed rotation of the motor (3000 RPM) to a lower, more usable wheel speed while significantly increasing the torque output. The chain drive ensures efficient power transfer with minimal slippage, providing a direct mechanical connection between the motor and the wheel. This allows for smooth acceleration, reliable traction, and efficient load handling. The tension in the chain is crucial for maintaining efficiency, as excessive slack can cause power losses, while excessive tightness can lead to wear and energy inefficiencies.

Mechanical transmission:

Fig.14. Mechanical transmission

In this power transmission system, it utilizes a two-stage mechanism, consisting of a belt drive followed by a chain drive, to efficiently transfer power from the engine to the rear wheel. Initially, the engine crankshaft rotates, and its motion is transmitted to a large pulley via a belt drive. The belt drive serves as the primary transmission stage, offering smooth power delivery, absorbing vibrations, and reducing sudden impact loads that could otherwise damage mechanical components. The belt drive also allows a slight amount of slippage, which helps in protecting the engine and drivetrain from excessive stress. This rotational power is then transferred to a secondary shaft, which has a sprocket mounted on it. At this point, the second stage of the transmission, the chain drive, takes over. The sprocket on the secondary shaft is connected to a larger sprocket on the rear wheel via a chain, ensuring direct power transfer with minimal losses. The chain drive provides a strong, high-torque connection between the intermediate shaft and the rear wheel, enabling the vehicle to move forward efficiently. The use of a belt drive in the first stage ensures durability and smooth operation, while the chain drive in the second stage ensures higher efficiency, better torque transmission, and reliable propulsion.

V.RESULTS AND DISCUSSION

Fig.15. Hybrid E-Vehicle Two Wheeler

The Hybrid E-Vehicle Two-Wheeler performed efficiently during testing, achieving speeds of 25–30 km/h in electric mode and 45 km/h in ICE mode. Battery backup lasted around 1.15 hours, and fuel efficiency was approximately 35–40 km/l. The motor produced 1.07 Nm torque after gear reduction, providing smooth acceleration. Power switching was seamless, and the system was structurally stable. Though regenerative braking and automatic switching were not included, the vehicle proved to be a reliable, eco-friendly, and cost-effective solution for short-distance travel.

VI. FUTURE ENHANCEMENTS

- Advanced Battery Technology
- Smart Energy Management System.
- Solar Charging Integration:
- Smart Vehicle Monitoring and IoT Integration

VII. CONCLUSION

The designing and fabrication of a hybrid electric two-wheeler focused on integrating both a Permanent Magnet DC (PMDC) motor and a 50cc Internal Combustion Engine (ICE) to achieve an efficient and sustainable transportation solution. The design process involved careful selection of components, including motor, battery, engine, and control systems, ensuring optimal power distribution and energy efficiency.

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