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Research Article

Design and development of a drive train for a hybrid two-wheeler

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Abstract:

The aim of this project is to focus on the design and fabrication of a hybrid two-wheeler system. As conventional fuel sources continue to deplete and global pollution levels rise due to the escalating number of vehicles, alternative fuels, and innovative concepts have gained prominence. The Hybrid Electric Vehicle (HEV) system is an effective solution. The project involves creating a two-wheeler (HEV) that harnesses both fuel-based and electric energy. The system integrates an internal combustion engine and an electric motor. Initially, the electric motor, i.e., connected to the rear wheel CVT clutch assembly by the belt drive, propels the vehicle using energy from the battery. Then, the internal combustion engine powers the vehicle. By rigorously testing and analyzing the performance of this hybrid two-wheeler in engine mode, electric mode, and hybrid mode, we aim to demonstrate its efficiency and compare it with conventional bikes. Ultimately, this vehicle holds the potential to significantly reduce pollution and fuel consumption and contribute to a sustainable future.

1. Introduction

In the ever-evolving landscape of transportation, the integration of cutting-edge technologies has paved the way for innovative solutions that cater to both efficiency and sustainability. One such groundbreaking development is the design and development of Hybrid Two-wheelers, a fusion of an internal combustion engine and an electric motor, each powered by a rechargeable battery pack. This amalgamation not only signifies a leap forward in the realm of two-wheeled mobility but also provides riders with unprecedented flexibility. The core principle of hybrid two-wheelers lies in harnessing the strengths of both combustion and electric technologies, allowing riders to seamlessly switch between power sources based on their specific needs and prevailing conditions.

1.1 Parallel hybrid configuration

One of the fundamental designs within the realm of hybrid two-wheelers is the parallel hybrid configuration. In this innovative setup, an electric motor and an internal combustion engine are intricately coupled, providing the capability to power the vehicle either individually or collaboratively. The integration of automatically controlled clutches plays a pivotal role, allowing for the seamless transition between the internal combustion engine and the electric motor. During electric driving, the clutch isolates the internal combustion engine while engaging with the gearbox, enabling efficient and eco-friendly propulsion. Conversely, in combustion mode, the engine and motor synchronize, working in tandem to deliver optimal performance. As we delve into the intricacies of the hybrid two-wheeler design, a fascinating world of dual-power dynamics unfolds, promising a new era in sustainable and versatile transportation.

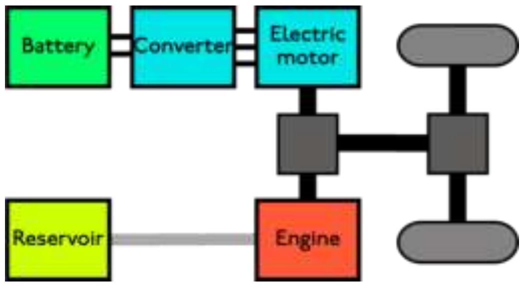

Figure 1. *Parallel Hybrid Vehicle*

Traditional two-wheelers have drawbacks like lower fuel efficiency, emissions, and noise pollution. Hybrid two-wheelers address these issues by combining internal combustion engines with electric propulsion, improving fuel efficiency, reducing emissions, and providing a quieter ride. They also offer environmental benefits, increased range with electric power, and compliance with stricter regulations. Despite considerations like battery production impact, hybrids present a more sustainable and efficient alternative in the evolving landscape of transportation. making hybrid options increasingly attractive for those seeking more sustainable and efficient modes of transportation.

2. Overall aim

This report aims to detail the conceptualization, design, and construction of a hybrid two-wheeler system that stands as a beacon of innovation in the face of dwindling traditional fuel resources and escalating global vehicular pollution. This project seeks to foreground the Hybrid Electric Vehicle (HEV) as a viable and effective alternative, showcasing its potential to revolutionize urban transportation.

At the heart of this endeavor is the creation of a two-wheeled HEV that synergistically combines the strengths of fuel-based and electric power. The vehicle is engineered to integrate an internal combustion engine seamlessly with an electric motor, which initially propels the Vehicle via a belt-driven connection to the rear wheel's CVT clutch assembly. After this, the internal combustion engine takes over the propulsion. This report aims to validate the HEV's operational efficiency and its superiority over traditional motorcycles through meticulous testing and comparative analysis across engine, electric, and hybrid modes. The ultimate goal is to demonstrate that this hybrid two-wheeler can significantly curtail pollution and fuel consumption which contributes to a more sustainable and environmentally friendly future.

3. Calculation for transmission mechanism

3.1. Specification of the vehicle

Table 1. *Specification of Engine*

Particulars	Details
Engine	109cc, 4 Stroke, Single cylinder
Power	8 bhp @ 7500 rpm
Torque	8.83 Nm @ 5500 rpm
Transmission	Automatic (V-Matic)
Fuel System	Carburetor
Ignition	CDI (Capacitor Discharge Ignition)
Starting Mechanism	Self-start and kick-start

The tables above show the engine specifications used in this project; these values are taken from the manuals and catalogs provided by the manufacturer (Make & Model: HONDA & Activa, Year:2008).

3.2. Specification of motor and battery

Table 2. *Specification of BLDC Motor*

Particulars	Details
Power	1000W
Voltage rating	48V
Speed	3500 rpm
Power Source	Battery

Table 3. *Specification of Battery*

Particulars	Details
Voltage rating	48V
Capacity	10Ah
Battery type	Lithium ion

3.3 Calculations for power and torque requirement from the motor and battery combination

3.3.1 Torque obtained from bike

Max Power - 7.86PS or 007.86N-m @ 8000rpm Max Torque 8.90N-m @ 5500rpm
Torque Required,
$P = 2\pi NT/60$
$T = 60 \times P/2\pi V = 60 \times 7.6/2\pi \times 1000$
$T = 7.123$ N-m
Initial speed required for converting Electric to IC Engine should be equal to or more than 20Km/hr.
In new design, drive will be connected to CVT hub at the driven wheel, and the wheel will rotate 1 rotation with 10 rotation of the hub.

3.3.2 Vehicle dimensions

Wheel Diameter: 406.4 mm (16 in)
Circumference= $2\pi R=2*\pi*203.2=1276.90$ mm
10 rotations of the hub will rotate 1 rotation of Wheel (10:1)
Wheel Rotation = 3500/10 = 350 rpm
Wheel distance covered = 383072.64 mm/min = 22984358.4 mm/hr
Vehicle speed = 22.98 km/hr
By considering 3500 rpm, vehicle can reach more than 20 Km/hr

3.3.3 Torque available from the motor with battery

$T = (P*60)/(2*\pi*N)$
$= (1000 * 60)/(2 * 11*3500)$
$= 2.72$ Nm
Since the hub to wheel speed ratio 10:1 (i.e. for wheel 1:10)
Therefore, Nwheel = 3500/10 = 350rpm
$P = (2\pi \text{Nwheel Twheel})/60$
$\text{Twheel} = (P*60)/(2*\pi*N)$
Twheel = 7.28 Nm
∴ Torque available at wheel is 7.28 Nm
Torque available is more than torque required. Therefore, the selected motor can be used for electric propulsion.

3.3.4 Current required for new motor

$P = V*I$
$I = 1000/48$
$I = 20.83$ Amps

3.3.5 Total run time from battery

B = 10000 mAh
V = 48V
∴ Available running time from above motor,
Time (min) = (10 / 20.83) *60
Time (min) = 28.80 min

4. Components used

This hybrid two-wheeler system has below major components,
1. 48V 1000W Brushless Motor
2. Brushless Controller for 1000W 48V BLDC Motor
3. 48v 10AH Lithium Ion Battery
4. 25mm V belt Pulley
5. Fenner 4PK875 Poly V belt
6. 12V 10A SPDT Relays
7. 5V 2A SPDT Relays

4.1. 48V 1000W Brushless Motor

48V BLDC motor 3 phase brushless DC motor with 2.72 Nm rated torque, max torque can up to 7.28 Nm, 3500 rpm rated speed and 20.83 rated current. 1000W high torque motor runs smoothly, with little interference, long life and low maintenance cost. Motor specifications are specified below,

Figure 2. *1000W 48V BLDC Motor*

Specifications:
1. Rated Power: 1000W
2. Rated Voltage: 48V
3. Rated Current: 20.83A
4. Phase: 3 phase
5. Rated Torque: 2.72 Nm
6. Max Torque: 7.28 Nm
7. Rated Speed: 3500 rpm
8. No-load Current: ＜6.5A
9. Square Flange Size: 86 mm
10. Working Efficiency: 85%

4.2. Brushless Controller for 1000W 48V BLDC Motor

A BLDC motor controller regulates the speed and torque of the motor; it can also start, stop, and reverse its rotation. Electronic commutation allows for faster current switching. It results in higher torque, effective speed control over a wide range, and hence improved motor performance and protecting against overloads and electrical faults. This system uses rated voltage of 48V as motor and rated current is 50A.

Figure 3. *1000W 48V BLDC Motor controller*

4.3. 48v 10AH Lithium Ion Battery

Here, the system used a 10Ah 48V lithium-ion battery, chosen for its optimal balance of capacity, voltage, and size. Integrated seamlessly into our system, this compact yet powerful battery serves as the primary power source, driving motors, sensors, and control systems with a steady stream of electricity. This battery has cell model BAK2550 mAh 3C EV grade and charge cycle 1200 plus with full capacity. Below details are provided by the manufacturer.

1. 13s40A, with Heat Sink protection
2. Thermal sensor Protection - YES
3. Maximum Battery Capacity: 10AH or 10,000 mAh
4. Battery Energy – 480wh
5. Maximum discharge current - 30A
6. Maximum charging current - 10A
7. Battery standard voltage - 48v
8. Battery full charge voltage – 54.4v
9. Battery Low discharge voltage- 42v
10. Standard Charging Temperature – 0°C to 45°C
11. Discharge Temperature -20°C to 45°C
12. Storage Temperature – 20°C to 45°C
13. Life Cycles – 1000 Plus at 80% DOD (Life increases at low DOD)
14. Charging Mode – CC/CV
15. Over Charge Protection in BMS – 54.6V (4.2V per Cell)
16. Deep Discharge Protection in BMS – 37V (2.85V per Cell)

Figure 4. *10Ah 48V Lithium-ion battery*

4.4. 25mm V belt Pulley

Pullies are used for the transmission of power from motor to the CVT clutch, which has same diameter having 4 grooves for the V belt. The pullies have diameter of 100mm made up of steel and have width of 25mm.

Figure 5*. 25mm V belt pulley*

Figure 6. *Fenner 4PK875 Poly V belt*

4.5. Fenner 4PK875 Poly V belt

Here, Poly-V Belt, or Ribbed Belt has longitudinal V-shaped ribs running along the inside of the belt. This will provide more efficient power transmission. This belt is made up of poly fabric and has 25mm belt width.

4.6 12V 10A SPDT Relays

SPDT relays are commonly used in control systems, where they can be used to switch between two different circuits or to switch a single circuit on or off. Here switching circuit uses 12V 10A automobile grade relays which switches IC to EV and vice versa by using Vehicles battery power.

4.7 5V 2A SPDT Relays

These SPDT relays are used to maintain circuit fully closed and maintains the initial EV mode till the vehicle reaches initial speed requirements. The coil rating is 5 volts and 2 amps.

Figure 7. *12V 10A relay*

Figure 8. *5V 2A relay*

5. Conceptual Design

Figure 9. *Conceptual design of assembly*

Figure 10. *Side view of fabricated drive*

The above images in figure 9 and 10 show the engine modification for the conversion from engine to hybrid mode. This will switch the mode based on the speed of the engine flywheel. In conventional transmission system, the bels drive works on CVT (continuously variable transmission) technology where power is transmitted by pulleys through belt drive. In this system, initial transmission of power is done by motor till the bike catches up to the speed of 20 Kmph. Then the bike will be shifted to engine mod

6. Switch mechanism

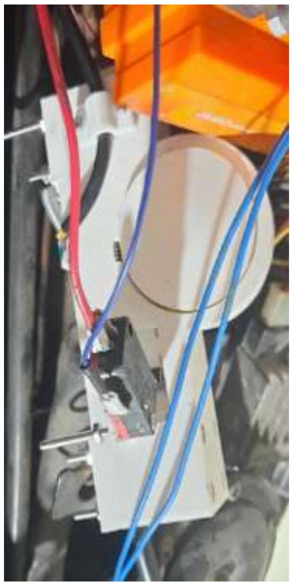

Figure 11. *5V Switch mechanism*

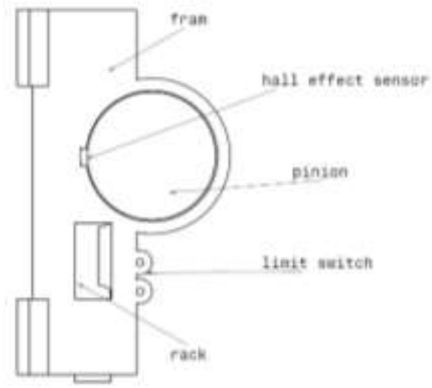

Figure 12. *5V components of switch mechanism*

The above mechanism is designed for switching EV mode to IC mode when the vehicle reaches its initial speed requirements. This design employs a rack and pinion mechanism integrated with a hall effect sensor and a permanent magnet to enable smooth transition and control of the vehicle's acceleration. The mechanism facilitates seamless switching between conventional and hybrid modes, enhancing overall performance and reducing energy consumption.

6.1. Working of switch mechanism

The system comprises a rack and pinion mechanism integrated with a hall effect sensor and a permanent magnet. The rack is connected to the accelerator cable, allowing it to move in tandem with the cable's operation. Simultaneously, the pinion is engaged with the rack, ensuring synchronized movement.

7. Battery Performance

7.1 Depth of Discharge (DoD)

Depth of Discharge (DoD) refers to the percentage of a battery's total capacity that has been discharged or used. It's a measure of how much energy has been taken out of the battery relative to its total capacity.
For the above selected battery, life cycles are more than 1000 at 80% DOD (life increases with low DOD) which is given by the manufacturer.

7.2 State of charge

The State of Charge (SoC) of a battery refers to the amount of energy remaining in the battery compared to its full capacity. Depth of Discharge (DoD) refers to the percentage of the battery's capacity that has been discharged.
Consideration done for calculating State of Charge (SoC) for a Depth of Discharge (DoD) are,
- Life Cycles – 1000 Plus at 80% DOD (Given by Manufacturer)
- Runtime of 25 minutes (By considering 25 times to start and stop during each run time)
- load condition of 20.33Amps for a battery with a capacity of 10Ah (48V motor current consumption).

Then,
Discharged Capacity=Load (A)×Time (hours) for a 25-minute runtime (0.4167 hours).
Discharged Capacity = 20.33A×0.4167 hours
= 8.471Ah (it means 80% of the battery's capacity has been used. Since the total capacity is 10Ah, the used capacity at 80% DoD)
Used Capacity = Total Capacity × DoD
Used Capacity = 10Ah×0.8=8Ah
SoC (remaining capacity) = Total Capacity−Used Capacity
SoC=10Ah−8Ah=2Ah
SoC as a percentage of the total capacity
SoC (%) = (Total Capacity Remaining Capacity) ×100
SoC (%) = (10Ah2Ah) ×100=20%
Therefore, after a 25-minute run under a load of 20.33Amps, the battery with an initial capacity of **10Ah at a DoD of 80% would have a State of Charge of 20%.**

Table 4. *Specification of BLDC Motor*

Time (Min)	Load(A)	Discharge Capacity (Ah)	DoD (%)	SoC (%)
0	0	0	0	100
5	20.33	1.6942	16.942	83.058
10	20.33	3.3884	33.884	66.116
15	20.33	5.0826	50.826	49.174
20	20.33	6.7768	67.768	32.232
25	20.33	8.471	84.71	15.29

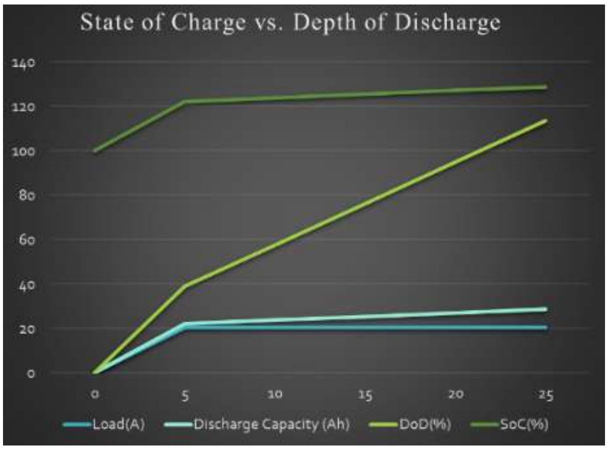

Figure 13. *Graph for State of Charge vs. Depth of Discharge*

8. Results and Discussion

Initially at Conventional Mode, the tried and tested method where the vehicle operates solely on the fuel engine, achieves a respectable mileage of 42 kilometers per liter. This metric serves as a reassuring baseline, demonstrating the vehicle's efficiency when relying solely on traditional combustion power.

8.1 Checking method: Full Tank to Full Tank (Conventional Mode)

Mileage: 42 km/l

Transitioning into Hybrid Mode, where the vehicle integrates both the fuel engine and battery power, the mileage significantly improves to 57 kilometers per liter. This enhancement is attributed to the hybrid system's ability to intelligently manage power sources, utilizing the electric motor to supplement propulsion and reducing the workload on the fuel engine. Crucially, battery recharge further optimizes efficiency, allowing the vehicle to harness regenerative braking and other energy recovery methods to replenish battery reserves during operation.
Overall, the Hybrid Mode's notable improvement in mileage underscores the effectiveness of hybrid technology in maximizing fuel economy and reducing environmental impact, marking a significant advancement beyond the capabilities of the conventional fuel-only Mode.

8.2 Hybrid Mode (With Recharge)

Mileage: 57 km/l

Performance Evaluation:
The hybrid system, when supplemented with battery recharge, significantly improves the vehicle's

mileage. This is the efficiency of the vehicle using only the fuel engine. It's a baseline for comparison with the hybrid mode.

8.3 Discussions

8.3.1 Analysis of Findings

The hybrid two-wheeler system designed and fabricated in this project significantly addresses environmental concerns associated with conventional vehicles. The system's ability to operate in engine, electric, and hybrid modes offers flexibility and efficiency. The performance analysis indicates that the hybrid two-wheeler can maintain optimal energy utilization, which is a testament to the effectiveness of integrating an internal combustion engine with an electric motor.

8.3.2 Comparison with Conventional Bikes

When compared to traditional motorcycles, hybrid two-wheelers exhibit a marked improvement in fuel efficiency and a reduction in emissions. This comparison is vital as it highlights the potential of hybrid systems to transform the two-wheeler industry by providing a more sustainable mode of transportation without sacrificing performance.

8.3.3 Limitations and Future Research

While the project's outcomes are promising, there are limitations to consider. The current design may require further refinement to enhance its practicality for everyday use. Additionally, long-term studies on the durability and maintenance of the hybrid system will be essential. Future research should focus on improving battery technology, exploring alternative construction materials, and developing more efficient power management systems.

9 Conclusion

In conclusion, the project's exploration into the design and fabrication of a hybrid two-wheeler system has yielded promising results. Integrating an IC engine with an electric propulsion presents a viable pathway to addressing the dual challenges of depleting conventional fuel sources and rising global pollution levels. This project's hybrid two-wheeler (HEV) demonstrates a significant leap in vehicular technology by efficiently harnessing fuel-based and electric energy.

Through rigorous testing and analysis, the HEV has shown superior performance in various modes of operation engine, electric, and hybrid compared to conventional motorcycles. The initial propulsion using the electric motor followed by the activation of the internal combustion engine exemplifies a seamless transition between power sources, a testament to its reliability and efficiency, optimizing energy utilization and reducing emissions.

The findings of this project underscore the HEV's potential to revolutionize the two-wheeler industry by offering an eco-friendly alternative that does not compromise performance. By significantly reducing pollution and fuel consumption, the hybrid two-wheeler is a testament to the potential of innovative vehicular designs to contribute to a sustainable future. it leads towards green transportation, aligning with global efforts to mitigate environmental impact and fostering a new era of mobility.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
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