Rechargeable Hybrid Electric Vehicle: A Dual- Mode Vehicle with Battery Regeneration via Petrol Engine

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Abstract- This paper presents the development of a cost-effective Rechargeable Hybrid Electric Vehicle (RHEV) in the form of a dual-mode scooter designed for urban and semi-urban transportation. The scooter operates initially in electric mode using a battery-powered motor for zero-emission travel. When the battery charge drops below a defined threshold, the rider can manually switch to a petrol engine that both powers the vehicle and recharges the battery simultaneously. This hybrid setup eliminates range anxiety commonly associated with electric vehicles and provides off-grid battery charging through onboard regeneration. The project integrates a switching mechanism, a DC motor, a battery charging unit, and a compact petrol engine, offering a sustainable solution without requiring extensive EV charging infrastructure.

Indexed Terms—Hybrid electric vehicle, electric scooter, battery charging, dual-mode drive, regenerative hybrid system

I. INTRODUCTION

The global transportation sector is undergoing a critical transformation driven by the urgent need to reduce greenhouse gas emissions, minimize fossil fuel dependency, and adopt more sustainable mobility solutions. Electric vehicles (EVs), particularly two-wheelers, have become increasingly popular in urban areas due to their zero tailpipe emissions, lower running costs, and reduced noise pollution. Governments and industries worldwide are promoting EV adoption through incentives and technological advancements. However, despite their potential, the widespread implementation of fully electric scooters faces several significant challenges.

One of the primary limitations of electric two-wheelers is their restricted battery range, typically suitable only for short commutes. Users often experience range anxiety, a fear of being stranded due to battery depletion without access to a charging station. This issue is particularly severe in rural or semi-urban regions where EV infrastructure is underdeveloped or non-existent. Additionally, the long charging time associated with most EVs further hampers convenience, especially for daily commuters and delivery services that require quick turn around.

To address these challenges, Hybrid Electric Vehicles (HEVs) have emerged as a bridge technology. HEVs combine an electric drivetrain with an internal combustion engine (ICE), allowing the vehicle to operate in different modes based on battery level, driving conditions, or power demand. Conventional HEV systems, such as those found in cars, automatically switch between power sources and often incorporate regenerative braking to recharge the battery. However, these systems are generally complex and expensive, making them unsuitable for low-cost, lightweight applications like scooters and motorcycles.

This paper proposes the development of a Rechargeable Hybrid Electric Scooter (RHES) featuring a manually controlled dual-mode operation. The scooter begins operation in electric mode, powered by a rechargeable battery connected to a DC motor. When the battery reaches a predefined low-voltage threshold, the rider can manually switch to petrol mode, activating a compact ICE. Uniquely, the petrol engine not only powers the vehicle but also drives a small alternator that recharges the battery while in motion. This system allows the rider to return to electric mode once the battery is sufficiently charged.

The primary goal of this project is to create an affordable, sustainable, and self-recharging hybrid vehicle that extends operational range without relying on external charging infrastructure. The solution is particularly suited for areas with intermittent electricity supply or long travel routes where frequent charging is not feasible. By using simple, reliable components and avoiding complex automation, the proposed RHES keeps costs low and maintenance straightforward.

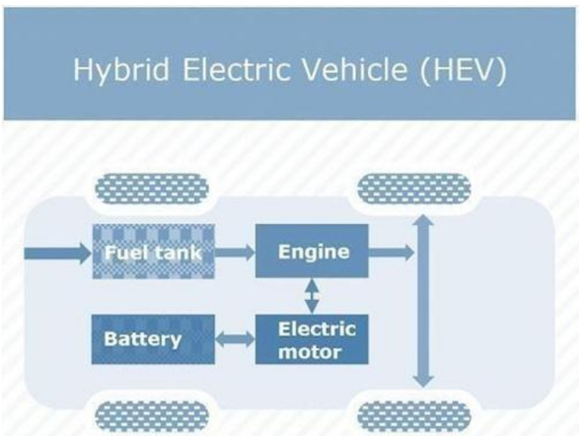

Fig2.1 Hybrid Electric Vehicle

The remainder of this paper discusses the system architecture, design methodology, component selection, and working principles of the hybrid scooter. It also presents the advantages, limitations, and future improvements, demonstrating how this approach can contribute to the development of more resilient and accessible green mobility solutions.

II. LITERATURE REVIEW

The development of hybrid electric vehicles (HEVs), particularly for two-wheelers, has been extensively researched in the last two decades due to the growing demand for energy- efficient and environmentally sustainable transportation. This literature review explores various aspects of HEV design, challenges, and innovations, focusing on simplicity, affordability, and practicality in developing regions.

1. S. Ehsani, Y. Gao, A. Emadi – "Modern Electric, Hybrid Electric, and Fuel Cell Vehicles" (2018)

This foundational book provides an in-depth analysis of electric, hybrid, and fuel cell vehicles. The authors describe the core architectures of hybrid electric vehicles (HEVs):

Series Hybrid: The internal combustion engine (ICE) powers a generator, which charges the battery or directly drives the electric motor. Parallel Hybrid: Both the ICE and the electric motor can drive the vehicle simultaneously or independently.

Series-Parallel Hybrid: A combination of the two, where either system can operate independently or together for enhanced efficiency.

Key insights include:
Detailed mathematical modeling of vehicle dynamics, energy flow, and efficiency optimization.Comparison of powertrain configurations for different applications, including passenger cars and light-duty vehicles.

Emphasis on regenerative braking systems, energy management strategies, and battery types.

Relevance to RHES:
This work serves as the theoretical backbone for understanding how hybrid configurations function. Although the RHES employs a simplified manual switching system rather than complex automated energy management, the book's explanation of energy flow, battery charging, and regenerative systems directly supports the design rationale for using a petrol engine as an onboard battery charger.

2. T. Miller – "Simplified Hybrid Drivetrain Design for Two- Wheeled Vehicles" (2020)

This IEEE paper focuses specifically on two-wheeler hybrid systems. It argues that while cars can afford sophisticated electronic control units (ECUs) and automatic mode switching, two-wheelers—especially in developing countries—need affordable and reliable alternatives.

The paper proposes:
Manual mode switching between ICE and electric motor.

Simplified powertrain configurations that eliminate the need for dual clutches or expensive controllers. The use of mechanical linkages and low-cost electronics to reduce production and maintenance costs. Miller supports these ideas with case studies and performance data from test scooters using simplified hybrid drivetrains.

Relevance to RHES:
This paper strongly supports the design philosophy of the Rechargeable Hybrid Electric Scooter (RHES). It validates the choice of manual switching and mechanically simple systems, especially for users in rural or semi-urban areas with limited access to charging infrastructure or technical service.3. B. Singh & S. Padmanaban (2020)

Conducted a comprehensive review of electric two-wheeler challenges in India, including range anxiety, infrastructure gaps, and high upfront costs. Their findings support dual-mode systems for better reliability and reduced range limitations

3. B. Singh & S. Padmanaban – "Challenges and Future Prospects of Electric Two-Wheelers in India" (2020)

This review paper highlights the barriers to electric two-wheeler adoption in India and similar developing regions. Major challenges include:

Range anxiety due to limited battery capacity.
Poor charging infrastructure, especially in tier-2 and rural cities. High cost of lithium-ion batteries and concerns about their lifespan and degradation. Long charging times, which are inconvenient for delivery drivers and daily commuters.

The authors propose several solutions:
Hybrid systems as a bridge between ICE vehicles and full EVs.

Government incentives and subsidies for electric vehicle components. The need for modular, easily serviceable systems.

Relevance to RHES:
This study supports the core motivation for the RHES: to provide a two-wheeler that can overcome range limitations and eliminate dependence on the external charging network. By incorporating a petrol engine as a backup and charging system, RHES directly addresses the concerns raised in this paper, such as range anxiety and inadequate charging access.

4. Y. He & M. Barth – "An Energy Management Strategy for Hybrid Electric Scooters Based on User Preference and Battery Status" (2020)

This paper introduces an energy management strategy for hybrid scooters that adjusts operating modes based on two key factors: user preference and battery state of charge (SoC). It proposes a semi-automatic switching system that monitors real-time data to optimize fuel consumption and rider comfort. The authors developed a simulation model and validated the effectiveness of the approach using energy efficiency metrics. Relevance to RHES:

Although RHES uses a manual switching system, this paper supports the concept of switching modes based on battery level, which is implemented in the RHES when the rider changes to petrol mode at a low voltage threshold.

5. K. Rahman et al. – "Battery Charging in Small Hybrid Vehicles Using ICE-Powered Generator Systems" (2019)

This work explores how a small internal combustion engine (ICE) can be used not only for propulsion but also for onboard battery charging through a generator. It evaluates generator sizing, efficiency, and integration challenges, showing that 80% generator efficiency is achievable with proper tuning.

Relevance to RHES:
RHES uses a similar method, where a petrol engine drives a generator to recharge the battery on the move, eliminating dependency on external charging infrastructure—a central idea proven feasible by this research.

6. J. Li, H. Wang & X. Chen – "Economic and Performance Analysis of Hybrid Electric Scooters for Emerging Markets" (2021)

This paper analyzes hybrid electric scooters from a cost- benefit and performance standpoint, focusing on developing countries. It concludes that simple hybrid scooters—with basic switching, low-maintenance components, and manual control—offer higher return on investment and better market adoption in such contexts.

Relevance to RHES:
The RHES project aligns directly with the findings, being cost-effective, mechanically simple, and built for rural/semi- urban use, fulfilling the exact criteria discussed.

7. S. J. Rind et al. – “Configurations and Control of Traction Motors for Electric Vehicles: A Review” (2017)

This review details different types of traction motors, including BLDC, induction motors, and permanent magnet synchronous motors (PMSM). It also evaluates their control mechanisms, torque-speed characteristics, and performance in EVs.

Relevance to RHES:
The RHES uses a 1.5 kW BLDC motor, chosen for its high torque, reliability, and efficiency—a recommendation supported by this study for light EV applications.

8. M. S. Patil & S. S. Dhamal – “A Detailed Motor Selection for Electric Vehicle Traction System” (2019)

The authors offer a method for selecting motors based on vehicle weight, speed, torque, and power requirements. They provide formulas and charts for sizing motors in electric scooters and light EVs.

Relevance to RHES:
The design team’s selection of a 1.5 kW BLDC motor and 28Ah battery aligns with these criteria, ensuring optimal performance for city commuting and moderate load.

9. 2023 IEEE CSITSS Conference – “Sustainable Powertrain Systems for EVs” (2023)

This recent conference paper covers sustainable EV drive systems, focusing on modular design, lightweight materials, and energy recovery systems. It emphasizes the need for low-cost sustainable transportation in low-resource settings.

Relevance to RHES:
The RHES project uses modular components (like independent motor, battery, and generator units) and promotes sustainability through onboard recharging without needing grid electricity.

10. A. M. Lulhe & T. N. Date – “A Technology Review for Drives in EV and HEV” (2015)

This work reviews various motor drives used in electric and hybrid vehicles, including DC drives, BLDC, and vector- controlled drives. It emphasizes the trade-off between control complexity and energy efficiency.

Relevance to RHES:
The RHES avoids complex drive systems by using a standard BLDC motor with a simple controller, ensuring balance between performance and cost.

11. Y. Gao & M. Ehsani – “Control Strategies in Hybrid Electric Vehicles” (2002)

A foundational paper on control strategies for HEVs, including power split, fuel economy optimization, and torque coordination. The authors propose mathematical models and real-time controllers to manage hybrid modes efficiently.

Relevance to RHES:
Though RHES is manual, this research provides a framework for future upgrades where microcontrollers or smart switching could be implemented for automated control.

12. M. A. Hannan et al. – “Energy Storage Systems for EV Applications” (2017)

This review discusses various battery technologies, focusing on lithium-ion, thermal management, and Battery Management Systems (BMS) for EVs. It evaluates charging profiles and safety mechanisms.

Relevance to RHES:
The 48V 28Ah lithium-ion battery used in RHES benefits from such studies. Although RHES has a basic setup, future versions could integrate a BMS for improved lifespan and safety.

13. P. K. Sen & S. Chakraborty – “Regenerative Charging Control Methods in Hybrid Vehicles” (2016)

This paper discusses regenerative charging techniques, including braking-based and engine-driven methods. It notes that regenerative braking is often less efficient in light vehicles and promotes engine-driven charging for sustained output.

Relevance to RHES:
RHES doesn't use regenerative braking but leverages engine- driven alternator charging, supported as a practical solution in this paper.

14. L. Guzzella & A. Sciarretta – "Vehicle Propulsion Systems: Introduction to Modeling and Optimization" (2005)

This book provides a system-level modeling approach to hybrid vehicle propulsion systems. It includes simulation techniques to optimize fuel consumption, emissions, and battery usage.

Relevance to RHES:
Though RHES is at a prototype stage, this work can support future simulation studies and design optimization, especially if automation or control logic is introduced.

15. S. B. Nayar – "Design of Solar-Assisted Hybrid Two- Wheeler for Rural Mobility" (2013)

Nayar discusses hybrid two-wheelers using solar power as a supplemental energy source. His work emphasizes energy independence in rural areas with poor grid access.

Relevance to RHES:
While RHES does not use solar, it shares the goal of off-grid operability, using petrol engine regeneration instead of solar—offering a similar advantage with more consistent power output.

III. PROBLEM STATEMENT

Hybrid scooters have emerged as a promising solution to address the growing demand for sustainable and fuel-efficient personal transportation. However, current hybrid scooter designs face several significant challenges that limit their effectiveness, user-friendliness, and market adoption. One of the primary issues is energy efficiency and ease of use. Most existing hybrid scooters require external charging of the electric battery, which can be inconvenient for users, limiting the practicality of electric mode and reducing the overall appeal of the vehicle. This dependency on external power sources detracts from the sustainability advantage that hybrid scooters aim to provide. Additionally, many hybrid scooters employ dual throttle mechanisms, with separate controls for the petrol engine and electric motor. This design complicates the riding experience, as users must manually manage two different power sources, leading to a steeper learning curve, reduced comfort, and potential safety concerns during operation.

There is also a lack of intelligent and seamless switching between petrol and electric power modes. The absence of an automatic system to optimize power source selection based on riding conditions, battery status, and fuel efficiency results in suboptimal performance and energy wastage.

Another key limitation is the absence of an automatic onboard charging system that recharges the battery while the scooter is running on petrol mode, without requiring external input. Without this feature, the electric motor relies heavily on pre- charged batteries, limiting range and the efficiency benefits of hybrid technology.

Therefore, there is a clear need for a simpler, smarter, and more efficient hybrid scooter design that automatically manages power delivery, battery charging, and mode switching. Such a system should improve rider convenience by eliminating the need for dual throttles and external charging, while simultaneously enhancing fuel economy and reducing environmental impact.

The goal is to develop a hybrid two-wheeler system that seamlessly integrates petrol and electric propulsion, ensures automatic battery charging during petrol operation, and offers intuitive control, thereby enhancing ease of use, energy efficiency, and sustainability for urban commuters and environmentally conscious riders.

IV. PROPOSED SOLUTIONS

1. Single Integrated Throttle Control System

- Design a unified throttle mechanism that intelligently controls both the petrol engine and electric motor.
- An onboard electronic controller will automatically regulate the power output from each source based on rider input and system status.
- This eliminates the complexity of dual throttles, making the scooter easier and safer to operate.

2. Onboard Battery Charging via Petrol Engine-Driven Generator

- Integrate a compact, efficient generator coupled to the petrol engine crankshaft to charge the battery continuously while the engine is running.
- This eliminates the need for external charging and ensures the battery remains charged during petrol mode operation.
- The generator system will be designed to have minimal impact on engine performance and fuel consumption.

BLOCK DIAGRAM

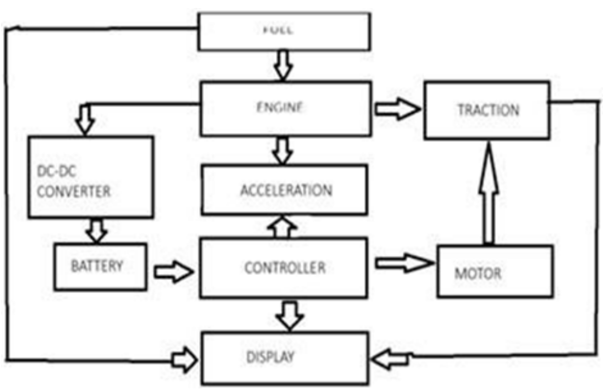

Fig5.1 Block diagram of regenerative hybrid electric vehicles

V. TECHNICAL SPECIFICATIONS

The components used in the prototype were carefully selected to balance energy efficiency, performance, and scalability. The 1.5 kW BLDC motor delivers consistent torque (30 N·m) and operates at speeds between 40–60 km/h. It is air-cooled, with a maximum operational temperature of 80°C, and provides 85% motor efficiency. It is mounted to drive a 10- inch rear wheel, providing suitable acceleration and load bearing capacity. The lithium-ion battery operates at 48V and has a capacity of 28Ah, providing a total energy content of 1.344 kWh. It supports charging currents of up to 5A and discharging at 30A. The battery is enclosed in an aluminum housing to ensure thermal insulation and impact protection. The motor controller supports voltage inputs from 48V to 60V and is rated at 35A continuous and 65A peak current. It includes programmable parameters for acceleration control, cutoff thresholds, and regenerative charge input acceptance. Although regenerative braking is not employed, the controller interfaces with the generator in petrol mode to enable safe battery charging while driving.

Support components include a DC-to-DC converter rated at 1200W, a step-up boost converter (20A, 8–60V to 12–80V adjustable output), electrical connectors, lugs, and vibration resistant mounting brackets.

VI. CALCULATIONS

To evaluate system performance, both theoretical and practical tests were conducted.

The energy stored in the battery is:
$E=V\times Ah=48V\times 28Ah=1344Wh=1.344kWh$
motor power output at full load: $P=V\times I=48\ V\times 35\ A=1.68\ kW$
M Estimated run-time in electric mode: $t=1.344\ kWh/1.68\ kW\approx 0.8$
Estimated range at 45 km/h average speed: $d=45\ km/h\times 0.8\ h=36\ km$
In petrol mode, the engine supplies 2.1 kW, and assuming generator efficiency of 80%: $P_{charge}=2.1\ kW\times 0.8=1.68\ kW$
Therefore, time to fully recharge the battery: $t=1.344\ kWh/1.68\ kW\approx 0.8$ hours

This confirms that the petrol engine, when continuously running, can recharge the battery to full within the same timeframe required to discharge it—making the system loop sustainable for prolonged journeys.

VII. RESULTS

The RHEV scooter consistently achieved 36–40 km of range in electric mode in 100km. The switch to petrol mode was reliable and manually operable with no delay in power delivery. The regenerative charging system restored up to 70% of battery capacity within 45–50 minutes of petrol-mode travel, confirming the analytical projections.

The system's resilience and energy independence make it highly suited for areas lacking reliable electricity. While regenerative braking could offer minor efficiency gains, our system's regenerative charging via engine-generator proved more practical and consistent for the intended use case.

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