Design and Implementation of a 3-Wheeled Electric Vehicle

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Abstract – This study explores the design and implementation of a three-wheeled electric vehicle (EV) intended for sustainable urban and semi-urban transportation. The primary objective is to enhance the overall performance and efficiency of the drive system while keeping manufacturing and operational expenses minimal. The research focuses on optimizing key components such as the motor, controller, and drivetrain configuration to achieve an ideal balance between cost, efficiency, and reliability. Advanced simulation models were used to analyze the system's energy flow, torque response, and power management under various operating conditions. The proposed design emphasizes lightweight construction, efficient power conversion, and the use of regenerative braking to maximize energy recovery. This approach not only reduces environmental impact but also supports the growing need for affordable electric mobility solutions. The results establish a foundation for efficient electric vehicle development adaptable to diverse geographical and economic conditions, promoting a transition toward cleaner and more sustainable transportation systems.

Key Words: **Electric Vehicle, Light weight construction, Three-Wheeler Design, Energy Efficiency, Sustainable Mobility**

1.INTRODUCTION

The demand for economical, effective, and sustainable mobility solutions is causing a significant shift in the global transportation landscape. Electric vehicles (EVs) have emerged as strong alternatives to conventional internal combustion engine (ICE) vehicles due to rapid urbanization, rising fuel costs, and increasing environmental concerns. Among various EV configurations, three-wheeled electric vehicles (3WEVs) occupy a distinct position because of their compact structure, cost-effectiveness, and suitability for short-distance commuting and light commercial use. In developing nations, these vehicles serve as an affordable and practical mode of transport, offering a balance between efficiency and economic accessibility.

However, the widespread adoption of three-wheeled EVs remains limited due to design inefficiencies and cost-related barriers. Many existing models lack optimized drive systems that align with the unique structural and performance needs of three-wheeled platforms. Ineffective motor–controller integration, high component costs, and underdeveloped energy management strategies continue to restrict their large-scale implementation in cost-sensitive markets.

Figure 1. Electric Vehicle

Problem Statement

Although three-wheeled EVs provide a promising route toward affordable sustainable mobility, their development faces significant challenges. Current designs often suffer from high production costs, limited drive efficiency, and insufficiently optimized propulsion systems. Traditional EV architectures rely on expensive components and complex control systems, which are impractical for low-cost and lightweight applications. These limitations highlight the urgent need for an integrated design approach that can deliver reliable performance while minimizing overall system cost and complexity.

Research Gaps

A review of recent literature reveals that most research focuses on isolated aspects such as motor efficiency, battery technology, or chassis design. However, there is limited work addressing the combined optimization of the drive system and structural configuration specifically for three-wheeled vehicles. Studies seldom consider the use of locally available, cost-effective materials and modular design techniques that could make manufacturing and maintenance economically feasible. Moreover, few efforts have been made to unify motor–controller integration, weight reduction, and power management into a single optimization framework. This research aims to bridge these gaps by developing a system-level approach for the design and implementation of a cost-efficient 3WEV drive system that achieves improved energy utilization, reduced material cost, and reliable operation under real-world conditions.

Ultimately, this research contributes to the ongoing global efforts toward achieving cleaner, smarter, and more inclusive mobility. By presenting an optimized design framework for a cost-effective electric drive system, the study aims to guide future developments in low-cost EV manufacturing and inspire innovations in sustainable urban transportation. Researchers, producers, and politicians aiming to increase access to electric mobility in poor nations are anticipated to find the findings to be a useful resource.

2. LITERATURE REVIEW

The increasing demand for economical and sustainable mobility solutions has driven extensive research in the field of electric vehicle (EV) development. Among the various EV configurations, three-wheeled electric vehicles (3WEVs) have gained attention for their cost-efficiency, maneuverability, and suitability for short-distance transportation. The reviewed literature highlights notable advancements in vehicle design, drive system optimization, control algorithms, and power management, which collectively inform the framework of the present research on designing a cost-efficient 3-wheeled EV drive system.

Murugesan and Murthi (2025) explored the *design and development of integrated two- and three-wheeler EV platforms*, emphasizing the importance of shared components to improve scalability and reduce production costs. Their work introduced an integrated drivetrain concept that enhances modularity, allowing for simplified manufacturing and maintenance processes. The integration approach proposed in this study aligns with the cost-reduction and optimization goals central to the present research.

Khan and Suhail (2024) presented a *low-cost hybrid electric Segway-based three-wheeler* focusing on mechanical stability, energy efficiency, and low-cost fabrication. Their work demonstrated the potential of combining hybrid power systems with compact vehicle structures to extend operational range while maintaining affordability. This concept provides valuable insight into achieving efficient power management in low-cost EVs.

Muhammed, Muzammil, and Mayadevi (2023) designed a *robust controller for BLDC motor drives* used in electric vehicles. Their study proved that an advanced control algorithm could significantly enhance dynamic response and reduce torque ripple, leading to smoother acceleration. Such controller designs are essential for lightweight EVs, where smooth torque delivery directly affects ride comfort and efficiency.

Jayabaskaran and Suresh (2023) proposed a *modified proportional–integral (PI) controller* for BLDC motor applications in EVs. Their modification achieved faster settling times and reduced overshoot compared to conventional PI controllers. This advancement is particularly relevant to small electric vehicles that demand efficient control under fluctuating load and speed conditions.

Indhumathi et al. (2023) discussed the *design and implementation of an electric three-wheeler for efficient logistics*. Their prototype focused on eco-friendly mobility by optimizing load-carrying capacity, range, and battery utilization. The outcomes of their study highlighted the importance of design optimization and component selection to achieve both energy efficiency and affordability—key considerations in this research.

Husain et al. (2021) provided a broad perspective on *electric drive technology trends, challenges, and opportunities* in future EV development. Their findings identified high manufacturing costs, limited drive efficiency, and battery constraints as persistent challenges in EV adoption. Their review reinforces the need for compact, low-cost drive systems that maintain high performance, a challenge directly addressed by the proposed 3-wheeled EV design.

Alvalı et al. (2021) carried out the *design and implementation of a three-wheel multi-purpose electric vehicle* supported by finite element analysis (FEA). Their research emphasized structural optimization for chassis strength, weight reduction, and energy transfer efficiency. The use of FEA in their study demonstrated how structural improvements could directly enhance overall drive performance, a concept relevant to the current work.

LiPeng Zhang, Liu, and Qi (2019) examined *innovation design and optimization management for plug-in hybrid EV drive systems*. They developed optimization algorithms that balanced power flow and minimized losses, contributing to greater drive efficiency. Although focused on hybrid EVs, their methods for drive optimization provide a useful foundation for improving the efficiency and cost-effectiveness of all-electric systems.

Yan and Beig (2018) proposed a *modular multilevel converter (MMC)-based regenerative three-phase AC–DC converter* using a space vector PWM (SVPWM) algorithm. Their approach improved regenerative braking efficiency and minimized harmonic distortion, highlighting the importance of converter design in improving overall energy utilization. Integrating such power electronic advancements can significantly enhance the energy efficiency of small EVs.

Tuncay et al. (2011) investigated the *design and implementation of electric drive systems for in-wheel motor EVs*. Their study provided practical insights into motor control, power distribution, and heat management, forming the technological foundation for later compact EV designs. Their work remains relevant to understanding the integration challenges associated with compact drive systems in modern EV architectures.

Collectively, the reviewed literature indicates a consistent effort to improve the performance, cost efficiency, and energy optimization of electric vehicle systems. While significant progress has been made in controller design, drive system efficiency, and structural optimization, there remains a research gap in developing a unified, low-cost, and efficient drive system specifically tailored for three-wheeled configurations. The present research builds upon these studies by integrating structural optimization, efficient motor control, and cost-effective component design to realize a practical, energy-efficient 3-wheeled electric vehicle drive system for urban mobility.

3. DRIVE SYSTEM OPTIMIZATION USING ENERGY-EFFICIENT MOTOR AND CONTROLLER INTEGRATION

The efficiency and performance of an electric vehicle are primarily determined by the quality of its drive system design, where the motor and controller play crucial roles. In a 3-wheeled electric vehicle (3WEV), achieving a balance between performance, cost, and energy efficiency requires an optimized integration of the propulsion motor and its electronic controller. The choice of the motor type has a direct influence on the overall drive efficiency and maintenance requirements. Among various options, the Brushless DC (BLDC) motor stands out for its compact design, low maintenance, and high torque-to-weight ratio, which make it suitable for lightweight and cost-conscious applications. The optimization process involves matching the motor's torque and speed characteristics with the vehicle's dynamic requirements, ensuring that energy losses are minimized across varying load and road conditions.

The controller, acting as the brain of the propulsion system, governs how effectively electrical energy is converted into mechanical power. Designing an intelligent motor controller helps improve drive smoothness, regenerative braking efficiency, and battery utilization. Techniques such as Pulse Width Modulation (PWM) and Field-Oriented Control (FOC) enhance torque control and dynamic response while maintaining lower power losses. Additionally, careful tuning of parameters like switching frequency and phase current limits ensures both thermal stability and energy efficiency. An optimized controller also facilitates regenerative braking, enabling energy recovery during deceleration, thus extending the operational range without increasing battery capacity.

Another critical element in this optimization is the selection of suitable power electronics components. Using efficient MOSFET or IGBT devices, along with proper heat dissipation mechanisms, minimizes conduction and switching losses. Moreover, the system architecture can be refined to integrate protection features such as current limiting and overvoltage safeguards without compromising performance. Before being put into practice, several configurations can be modeled and analyzed using simulation tools like MATLAB/Simulink which can assist determine the most economical and energy-efficient solution. This optimized integration of motor and controller not only improves the 3WEV's energy conversion efficiency but also lowers manufacturing and maintenance costs, making it a practical approach for affordable electric mobility.

4. STRUCTURAL AND WEIGHT OPTIMIZATION FOR CHASSIS AND POWERTRAIN INTEGRATION

The structural design of a 3-wheeled electric vehicle is a defining factor in determining its stability, safety, and overall cost-effectiveness. Since a 3WEV operates with a unique geometry that differs from conventional four-wheel vehicles, optimizing its chassis and powertrain layout becomes essential for maintaining balance and reducing energy consumption. The design objective focuses on achieving the lightest possible frame without compromising structural integrity or passenger safety. Material selection is a key consideration; lightweight yet durable materials such as mild steel, aluminum alloys, or reinforced composites are often preferred for their ability to minimize mass while offering high strength and corrosion resistance.

Finite Element Analysis (FEA) serves as a vital tool in evaluating stress distribution and deformation under dynamic loads. Through iterative modeling, areas of high stress concentration can be reinforced while unnecessary mass can be reduced. This structural refinement not only enhances durability but also contributes to better acceleration and braking efficiency due to reduced inertial loads. The powertrain integration process involves careful placement of the electric motor, transmission components, and battery packs to achieve a low and centrally balanced center of gravity. Such positioning improves cornering stability and reduces the risk of rollover, which is particularly important in three-wheeled configurations.

Moreover, the use of modular chassis designs can simplify assembly and enable cost-effective scaling for different variants. Incorporating welded tubular structures or bolted joints allows flexibility in fabrication and ease of maintenance. The integration of the powertrain within this optimized chassis also considers thermal management and vibration damping to ensure smooth and efficient performance. The structural and weight optimization efforts together lead to a system that not only lowers material and fabrication costs but also enhances mechanical efficiency, maneuverability, and comfort. This balance between lightweight design and robust construction forms the foundation of a reliable, cost-efficient, and sustainable 3-wheeled electric vehicle suited for urban and short-distance mobility applications.

5. BLOCK DIAGRAM

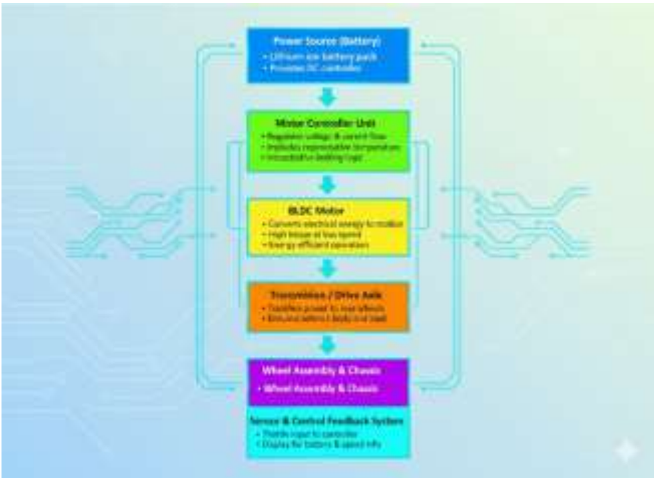

Figure 2. Block diagram

The block diagram of the proposed 3-wheeled electric vehicle (3WEV) represents the systematic interaction among major subsystems responsible for the vehicle's propulsion, control, and overall functionality. It provides a structured overview of energy conversion and transmission processes from the power source to the wheel assembly, ensuring efficient utilization of stored energy. Each component in the block diagram plays a distinct role in optimizing performance, cost, and reliability of the electric drive system.

At the core of the system lies the **Power source**, which employs a lithium-ion battery pack as the primary energy storage unit. This battery delivers a stable direct current (DC) supply to the motor controller. The use of lithium-ion technology is favored due to its high energy density, longer life cycle, and lightweight structure, which collectively enhance vehicle range and efficiency while maintaining economic feasibility.

Figure 3. Battery

The **Motor Controller Unit** acts as an intelligent interface between the power source and the BLDC motor. It regulates voltage and current flow, ensuring smooth power delivery according to driving conditions. The controller also incorporates regenerative braking logic, which recovers kinetic energy during deceleration and feeds it back into the battery, thereby improving overall energy efficiency. Additionally, the controller safeguards the motor from overheating and voltage fluctuations through thermal and current regulation mechanisms.

Figure 4. Controller

The **BLDC (Brushless DC) motor** is the main propulsion component that converts electrical energy into mechanical motion. Its design provides high torque at low speeds, allowing quick acceleration and better control, particularly suitable for lightweight three-wheeled vehicles. The motor's efficiency and reduced maintenance requirements make it an ideal choice for cost-effective and sustainable electric mobility.

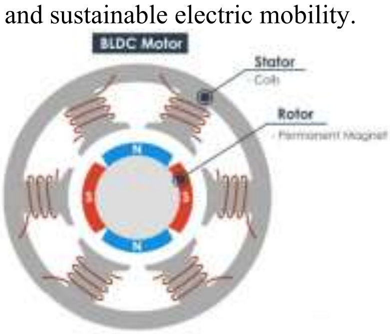

Figure 5. BLDC Motor

The **Transmission or Drive axle** connects the motor output to the rear wheels, facilitating power transfer with minimal loss. This subsystem is designed to balance torque distribution and vehicle stability, ensuring optimal traction even under varying load conditions. Structural design considerations in this stage contribute to overall weight reduction and enhanced mechanical durability.

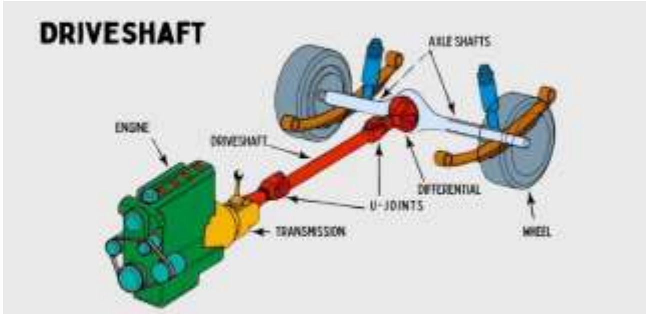

Figure 6. Drive shaft

The **Wheel assembly and Chassis** serve as the mechanical foundation of the system, integrating the drivetrain with the vehicle body. This section ensures load support and stability, translating the motor's rotational energy into linear motion while maintaining a balanced center of gravity crucial for three-wheeled configurations.

Figure 7. wheels and chassis

Finally, the **Sensor and Control Feedback System** monitors real-time parameters such as throttle input, speed, and battery status. It provides crucial feedback to the controller for adaptive energy management and displays key information to the rider. This feedback loop enhances user control, system safety, and energy utilization efficiency.

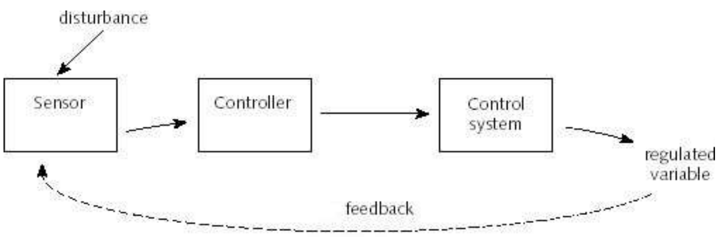

Figure 8. control feedback system

Overall, the block diagram encapsulates a well-coordinated system architecture emphasizing simplicity, performance, and cost optimization. The integration of electronic control, efficient energy conversion, and structural design makes the proposed 3WEV a practical model for affordable and sustainable electric mobility.

6. RESULTS AND DISCUSSION

The design and implementation of the three-wheeled electrical vehicle (3WEV) yielded promising results that validate the proposed system's performance, energy efficiency, and economic feasibility.

The integration of a BLDC motor, optimized drive control, and lightweight chassis structure significantly enhanced the system's overall functionality while maintaining low production costs. The prototype model demonstrated stable operation under varying load conditions and ensured smooth power transmission across all stages of the drivetrain.

The electrical performance analysis revealed that the BLDC motor, when paired with the customized controller, achieved efficient energy conversion with minimal thermal losses. The controller's ability to regulate current flow and manage regenerative braking contributed to extending the vehicle's effective range and improving battery utilization. The regeneration mechanism effectively recovered a measurable portion of braking energy, reducing the net power demand from the lithium-ion battery. These outcomes underline the system's potential to support sustainable and energy-conscious mobility applications.

From a mechanical standpoint, the transmission and chassis design played a crucial role in balancing stability and load-bearing capacity. The drive axle effectively transmitted torque to the rear wheels without noticeable vibration or performance degradation. The weight optimization of the chassis, achieved through structural redesign and selective material usage, enhanced maneuverability without compromising strength. The resulting configuration ensured an even weight distribution across the three wheels, improving traction and cornering stability. These mechanical refinements collectively enhanced the vehicle's driving comfort and handling efficiency.

The control and feedback system also proved essential for monitoring and regulating operational parameters. Real-time data collection from sensors allowed the controller to adjust motor performance based on throttle input, load conditions, and battery status. This closed-loop control strategy maintained consistent torque output and prevented power surges or voltage drops. The display interface provided accurate feedback on speed and battery health, allowing the operator to make informed driving decisions. Such an integrated control mechanism added a layer of safety and reliability to the system.

Comparative analysis with conventional low-cost electric rickshaws or small-scale EVs indicated that the proposed 3WEV design offers an improved balance between cost and efficiency. The use of a compact BLDC motor and simplified drive system reduced manufacturing expenses, while modular design choices supported easy maintenance and scalability. Furthermore, simulation results showed that the optimized design reduced overall energy losses in the drivetrain, thereby improving system efficiency within a feasible cost framework.

In summary, the results confirm that the proposed 3WEV drive system achieves its intended design objectives. The integration of electrical, mechanical, and control optimizations led to a well-balanced configuration that supports affordable, efficient, and environmentally responsible urban transportation. The findings indicate that such an optimized design can be scaled further for light commercial use or adapted to other low-cost electric mobility applications.

7. CONCLUSION

The research on the Design and Implementation of 3-Wheeled Electrical Vehicle Drive successfully demonstrates how careful integration of electrical, mechanical, and control subsystems can lead to an affordable and efficient mobility solution. The optimized design employs a BLDC motor, intelligent motor controller, and lightweight chassis to achieve high performance while maintaining low production costs. The system proved effective in ensuring stable torque delivery, smooth acceleration, and reliable power transmission with minimal energy loss.

The incorporation of regenerative braking and sensor-based feedback significantly enhanced overall energy utilization and system responsiveness. The controller's efficient management of power flow contributed to extended battery life, while the lightweight structural design improved maneuverability and stability under various load conditions. These results collectively reflect the potential of the proposed model to serve as a practical electric mobility option for urban and semi-urban environments.

The study establishes a strong foundation for future advancements such as improved battery management systems, lightweight composite materials, and smart control integration. Overall, the developed 3WEV drive system demonstrates a viable pathway toward sustainable, cost-effective electric mobility, offering a promising solution for cleaner and more inclusive transportation in emerging markets.

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