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Design and Development of a 60V Electric Vehicle Powertrain for a 4-Seater EV

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ABSTRACT: Electric vehicles (EVs) are rapidly emerging as a sustainable and energy-efficient alternative to conventional internal combustion engine (ICE) vehicles due to their ability to significantly reduce greenhouse gas emissions, air pollution, and dependence on fossil fuels. With increasing urbanization and the need for clean transportation, the development of low-cost and efficient EV systems has become a major area of research.

This paper presents the **design, development, and performance analysis of a 60V electric vehicle powertrain** for a 4-seater electric vehicle intended for short-range mobility applications. The proposed system integrates a **60V lead-acid battery pack (5 × 12V, 135Ah)**, a **1500W DC motor**, a **Pulse Width Modulation (PWM)-based motor controller**, and an onboard **AC–DC charging unit**. The powertrain is designed to deliver reliable performance with optimized energy utilization while maintaining cost-effectiveness.

A detailed design methodology is adopted, including component selection, electrical integration, and implementation of PWM-based speed and torque control. The controller regulates the average voltage supplied to the motor, enabling smooth acceleration, improved efficiency, and reduced switching losses. The system is evaluated under various operating conditions to analyze parameters such as speed, current consumption, efficiency, and load performance.

Experimental results indicate that the developed prototype achieves a **maximum speed of approximately 40 km/h**, with stable operation and efficient power delivery. The overall system demonstrates improved energy management, reduced mechanical complexity, and lower maintenance requirements compared to conventional vehicles. Although the use of lead-acid batteries introduces limitations such as increased weight and moderate energy density, the system remains economically viable for low-speed applications.

The proposed EV powertrain is particularly suitable for **campus transportation, short-distance urban commuting, and last-mile mobility solutions**. Furthermore, the design provides a scalable platform for future enhancements such as **lithium-ion battery integration, regenerative braking, fast-charging capabilities, and IoT-based monitoring systems**, thereby improving performance, efficiency, and user experience.

KEYWORDS: Electric Vehicle, Powertrain, Battery System, DC Motor, Motor Controller, PWM Control

I. INTRODUCTION

The rapid growth in global energy demand, coupled with the depletion of fossil fuel reserves and increasing environmental concerns, has created an urgent need for sustainable and energy-efficient transportation systems. Conventional vehicles powered by internal combustion engines (ICEs) are among the primary contributors to greenhouse gas emissions, air pollution, and noise pollution. These vehicles emit harmful gases such as carbon dioxide (CO₂), nitrogen oxides (NO_x), and particulate matter (PM), which significantly impact climate change and public health. In addition, the rising cost of fossil fuels and dependency on non-renewable energy sources further emphasize the necessity for alternative mobility solutions.



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Electric vehicles (EVs) have emerged as a promising solution to address these challenges by utilizing electrical energy stored in rechargeable battery systems. Unlike ICE vehicles, EVs produce zero tailpipe emissions, operate with higher energy efficiency, and offer quieter performance. Furthermore, EVs have fewer moving parts, resulting in reduced maintenance requirements and improved reliability. The advancement of power electronics, battery technologies, and motor control strategies has accelerated the adoption of EVs in various applications, including personal transportation, public transit, and industrial mobility.

A critical component of an electric vehicle is its **powertrain system**, which consists of the energy source (battery), power conversion unit (motor controller), electric motor, and associated subsystems. The performance, efficiency, and reliability of an EV largely depend on the optimal design and integration of these components. In low-speed and short-distance applications, such as campus mobility, industrial transport, and urban last-mile connectivity, cost-effective powertrain solutions are essential for practical implementation.

This work focuses on the **design and development of a 60V electric vehicle powertrain system for a 4-seater EV**, emphasizing simplicity, efficiency, and affordability. The proposed system employs a lead-acid battery pack, a DC motor, and a Pulse Width Modulation (PWM)-based motor controller to achieve controlled power delivery and smooth vehicle operation. The selection of a 60V architecture provides a balance between safety, performance, and system complexity, making it suitable for low-voltage EV applications.

The primary objective of this study is to develop a reliable and efficient EV powertrain that can meet the requirements of short-range transportation while minimizing cost and energy losses. The paper also evaluates system performance under practical conditions and highlights the advantages and limitations of the proposed design. Additionally, the work lays a foundation for future enhancements, including advanced battery technologies, intelligent control systems, and improved energy management strategies.

II. LITERATURE REVIEW

The development of electric vehicles (EVs) has been extensively studied in recent years, with a strong focus on improving energy efficiency, performance, and cost-effectiveness. A critical aspect of EV design lies in the selection of appropriate energy storage systems and motor control strategies, which directly influence vehicle range, reliability, and overall efficiency.

Energy storage technologies play a vital role in EV performance. Lead-acid batteries have been widely used in low-cost EV applications due to their affordability, ease of availability, and simple charging requirements. However, several studies highlight their limitations, including low energy density, higher weight, shorter cycle life, and longer charging times. In contrast, lithium-ion batteries offer significantly higher energy density, longer lifespan, and faster charging capabilities, making them more suitable for modern EVs despite their higher initial cost. Researchers have also explored advanced battery management systems (BMS) to improve safety, performance, and lifespan of battery packs.

Electric motor selection is another key factor in EV powertrain design. Brushless DC (BLDC) motors are commonly preferred in modern EVs due to their high efficiency, compact size, high torque-to-weight ratio, and low maintenance requirements. Their electronic commutation eliminates the need for brushes, reducing wear and improving reliability. Alternatively, conventional DC motors are still used in low-cost and small-scale applications due to their simple control and lower initial cost, although they suffer from reduced efficiency and higher maintenance needs compared to BLDC motors.

Motor control techniques have also been widely studied to enhance EV performance. Pulse Width Modulation (PWM) is one of the most commonly used control methods for regulating motor speed and torque. By varying the duty cycle of the input voltage, PWM allows precise control of the average voltage supplied to the motor, resulting in smooth acceleration and reduced energy losses. Advanced control techniques, such as field-oriented control (FOC) and vector control, have also been proposed for high-performance EVs, offering improved dynamic response and efficiency.

In addition, several research works emphasize the importance of integrating power electronics converters, efficient charging systems, and regenerative braking mechanisms to enhance overall system efficiency. Regenerative braking



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systems, in particular, have been shown to recover a portion of kinetic energy during braking and store it back in the battery, thereby improving driving range.

Despite these advancements, there remains a need for cost-effective and simplified EV powertrain designs suitable for low-speed and short-distance applications. This paper addresses this gap by focusing on the design and implementation of a **60V EV powertrain system** using readily available components, ensuring a balance between performance, efficiency, and affordability.

III. SYSTEM ARCHITECTURE

The system architecture of the proposed electric vehicle (EV) powertrain is designed to ensure efficient energy conversion, reliable operation, and cost-effective implementation. The powertrain consists of four major subsystems: the battery system, electric motor, motor controller, and charging unit. Proper integration of these components is essential to achieve optimal performance, efficiency, and durability of the vehicle.

A. Battery System

The battery pack acts as the primary energy source of the electric vehicle, supplying the required electrical power to drive the motor and associated electronics. The performance of the EV, including range and acceleration, largely depends on the battery specifications.

- Type: Lead-acid battery
- Configuration: $5 \times 12V$ batteries connected in series
- Total Voltage: 60V
- Capacity: 135Ah
- Stored Energy: ~8.1 kWh

In a series configuration, the voltages of individual batteries are added while maintaining the same current capacity, resulting in a 60V output. Lead-acid batteries are chosen for this design due to their low cost, availability, and ease of maintenance. However, they have relatively lower energy density and higher weight compared to lithium-ion batteries. The battery system must also consider important factors such as state of charge (SoC), depth of discharge (DoD), and thermal management to ensure longer lifespan and safe operation. Proper insulation and secure mounting are required to prevent vibration and mechanical damage during vehicle operation.





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B. DC Motor

The electric motor is responsible for converting electrical energy into mechanical energy to propel the vehicle. The choice of motor significantly affects efficiency, torque characteristics, and overall performance.

- **Type:** DC Motor
- **Power Rating:** 1500W
- **Rated Voltage:** 60V
- **Maximum Speed:** ~40 km/h
- **Operating Principle:** Electromagnetic induction

The DC motor operates by creating a magnetic field interaction between the stator and rotor, producing rotational motion. It is selected for this project due to its **simple control mechanism, low initial cost, and ease of implementation**. Although DC motors require periodic maintenance due to brushes, they are suitable for low-speed EV applications.

The motor is typically coupled with a **gear reduction mechanism**, which increases torque at the wheels while reducing rotational speed, enabling the vehicle to carry passengers efficiently under varying load conditions.



C. Motor Controller

The motor controller is a crucial component that manages the flow of electrical power from the battery to the motor. It determines the speed, torque, and direction of the motor based on driver input.

- **Control Technique:** Pulse Width Modulation (PWM)
- **Functions:**
 - Speed control



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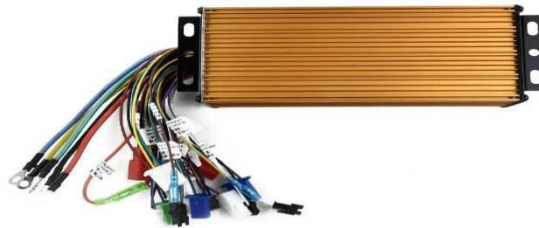
- Torque regulation
- Direction control (forward/reverse)
- **Switching Devices:** MOSFETs/IGBTs (typically used)

The controller uses PWM to regulate the **average voltage applied to the motor** by rapidly switching the supply on and off at high frequency. By adjusting the duty cycle of the PWM signal, the controller controls the motor speed smoothly and efficiently.

Key advantages include:

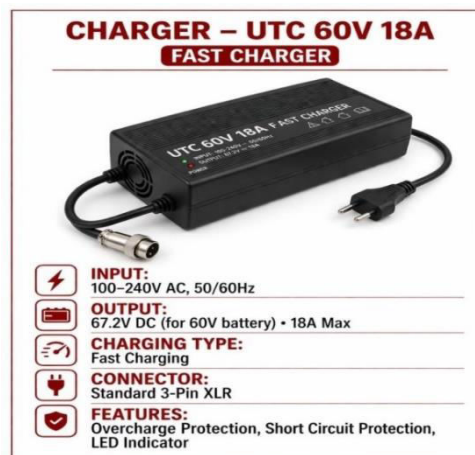
- High efficiency due to reduced switching losses
- Smooth acceleration and deceleration
- Better energy utilization
- Reduced heat generation

The controller also provides protection features such as **over-current protection, under-voltage cutoff, and thermal protection**, ensuring safe operation of the powertrain.



D. Charger

- The charging unit is responsible for replenishing the battery by converting AC supply from the grid into regulated DC power suitable for the battery pack.
- **Input Supply:** 220–240V AC
- **Output Voltage:** 60V DC
- **Charging Current:** 18A
- **Charging Type:** Constant Voltage / Constant Current (CV/CC)
- The charger operates in two main stages:
- **Constant Current Mode:** Supplies a steady current to quickly charge the battery
- **Constant Voltage Mode:** Maintains a fixed voltage while reducing current to prevent overcharging
- Proper charging is essential to extend battery life and ensure safety. The charger may include protection mechanisms such as **over-voltage protection, short-circuit protection, and temperature monitoring**.





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IV. METHODOLOGY

The development of the proposed electric vehicle (EV) powertrain system follows a systematic and structured approach to ensure optimal performance, efficiency, and reliability. The methodology involves component selection, system integration, control implementation, and experimental validation. Each stage is carefully designed to achieve a balance between cost, performance, and ease of implementation.

A. Selection of Components

The first step involves selecting suitable components based on the required vehicle specifications such as load capacity, speed, and range.

- **Battery Selection:**

A 60V lead-acid battery pack ($5 \times 12V$, 135Ah) is chosen considering cost-effectiveness, availability, and ease of charging. The capacity is selected to meet the desired driving range and load requirements.

- **Motor Selection:**

A 1500W DC motor rated at 60V is selected to provide sufficient torque and speed for a 4-seater EV. The motor rating is determined based on vehicle weight, expected load, and terrain conditions.

- **Motor Controller Selection:**

A PWM-based motor controller is chosen for its high efficiency, simplicity, and ability to provide smooth speed and torque control.

- **Charger Selection:**

A 60V, 18A charger is selected to ensure safe and efficient charging of the battery pack within a reasonable time.

The selection process ensures compatibility among all components in terms of voltage, current, and performance requirements.

B. Electrical Integration

The electrical integration involves proper interconnection of all components to form a complete powertrain system.

- The battery pack is connected in series to obtain the required 60V output.
- The battery output is connected to the motor controller through appropriate protection devices such as fuses and circuit breakers.
- The motor controller is connected to the DC motor to regulate power flow.
- The charging unit is integrated with the battery pack for recharging purposes.

Proper wiring, insulation, and connectors are used to minimize losses and ensure safety. Voltage and current ratings of all cables are carefully selected to handle peak load conditions.

C. Mechanical Integration

Mechanical integration involves mounting and aligning all components within the vehicle chassis.

- The battery pack is securely mounted to maintain stability and minimize vibration.
- The motor is coupled to the drivetrain using a suitable transmission system (chain drive or gear mechanism).
- Proper alignment is ensured to reduce mechanical losses and wear.
- Structural support is provided to handle load and road conditions.

This step ensures durability, safety, and efficient transfer of mechanical power to the wheels.

D. Implementation of PWM-Based Control

The motor controller utilizes Pulse Width Modulation (PWM) to regulate the speed and torque of the motor.

- The PWM signal controls the average voltage applied to the motor by varying the duty cycle.
- A higher duty cycle results in higher motor speed, while a lower duty cycle reduces speed.
- The controller responds to driver input (accelerator) to adjust the duty cycle in real time.

This method ensures:

- Smooth acceleration and deceleration
- Reduced power losses
- Improved efficiency and performance



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E. Testing and Performance Evaluation

After integration, the system is tested under various operating conditions to evaluate performance and reliability.

- **No-load Testing:** Verifies basic operation of motor and controller
- **Load Testing:** Evaluates performance under different passenger loads
- **Speed Testing:** Measures maximum achievable speed
- **Efficiency Analysis:** Determines energy consumption and losses
- **Thermal Testing:** Observes temperature rise in battery and controller

Performance parameters such as voltage, current, speed, and power consumption are recorded and analyzed.

F. Safety and Protection Measures

To ensure safe operation, the following protection mechanisms are implemented:

- Over-current protection
- Short-circuit protection
- Over-voltage and under-voltage protection
- Thermal protection for battery and controller

These measures enhance system reliability and prevent damage to components.

V. WORKING PRINCIPLE

The working principle of the proposed electric vehicle (EV) powertrain is based on the efficient conversion of electrical energy stored in the battery into mechanical energy required to drive the vehicle. The system operates through the coordinated functioning of the battery, motor controller, electric motor, and transmission system.

Initially, the **battery pack (60V)** acts as the primary energy source and supplies direct current (DC) power to the motor controller. The energy stored in the battery is delivered through properly rated cables and protection circuits to ensure safe and stable operation.

The **motor controller** plays a key role in regulating the power supplied to the motor. It uses **Pulse Width Modulation (PWM)** to control the average voltage and current delivered to the motor. By rapidly switching the supply ON and OFF at a high frequency, the controller adjusts the duty cycle of the PWM signal based on the driver's input (accelerator position). A higher duty cycle increases the average voltage, resulting in higher motor speed, while a lower duty cycle reduces the speed. This method enables precise control of both speed and torque with high efficiency and minimal energy loss.

The controlled electrical power is then supplied to the **DC motor**, which converts electrical energy into mechanical energy based on electromagnetic principles. When current flows through the motor windings, it generates a magnetic field that interacts with the stator field, producing rotational motion of the rotor. The speed of rotation is directly proportional to the applied voltage, while the torque depends on the current supplied.

The mechanical output from the motor is transmitted to the wheels through a **mechanical transmission system**, such as a chain drive or gear reduction mechanism. This transmission system plays an important role in increasing torque and adjusting speed to match the vehicle's operational requirements. The wheels rotate as a result, propelling the vehicle forward.

During operation, the system continuously responds to variations in load conditions, such as changes in passenger weight or road inclination. The motor controller dynamically adjusts the PWM duty cycle to maintain smooth and stable performance. Additionally, protective mechanisms within the controller ensure safe operation by preventing over-current, over-voltage, and overheating conditions.

Overall, this coordinated operation ensures:

- Smooth and controlled acceleration
- Efficient utilization of electrical energy
- Reduced energy losses and heat generation
- Reliable and stable vehicle performance



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Thus, the proposed powertrain system provides an effective and practical solution for low-speed electric vehicle applications, particularly in short-distance and urban mobility scenarios.

VI. RESULTS AND DISCUSSION

The performance of the developed 60V electric vehicle (EV) powertrain was evaluated through a series of experimental tests under different operating conditions. The results obtained demonstrate the effectiveness of the system in terms of speed, efficiency, and reliability for short-distance transportation applications.

A. Performance Analysis

The experimental evaluation of the EV powertrain indicates satisfactory performance in real-time conditions.

- **Smooth Acceleration:**

The use of a PWM-based motor controller ensures gradual and controlled increase in motor speed. The vehicle exhibits smooth acceleration without sudden jerks, enhancing driving comfort and reducing mechanical stress on components.

- **Efficient Energy Utilization:**

The system efficiently utilizes the available battery energy by minimizing losses in the controller and motor. The PWM technique enables optimized voltage control, resulting in improved overall efficiency of the powertrain.

- **Maximum Speed:**

The vehicle achieves a maximum speed of approximately **40 km/h**, which is suitable for applications such as campus transport, industrial mobility, and short-distance urban commuting.

- **Stable Operation:**

The system maintains consistent performance under varying load conditions, including different passenger weights and minor road gradients. The controller dynamically adjusts power delivery to ensure stable operation.

- **Thermal Performance:**

During testing, moderate temperature rise was observed in the motor and controller, remaining within safe operating limits. This indicates proper energy management and minimal excessive losses.

B. Advantages

The developed EV powertrain offers several notable advantages:

- **Zero Emissions:**

The system produces no tailpipe emissions, making it environmentally friendly and suitable for reducing air pollution in urban areas.

- **Low Maintenance Cost:**

Compared to internal combustion engine vehicles, the EV powertrain has fewer moving parts, resulting in reduced wear and lower maintenance requirements.

- **Cost-Effective Design:**

The use of lead-acid batteries and a DC motor reduces the overall system cost, making it economically viable for small-scale and low-speed applications.

- **Simple Architecture:**

The system design is straightforward, enabling easy implementation, troubleshooting, and scalability.

- **Noise Reduction:**

The electric motor operates with minimal noise, contributing to a quieter and more comfortable driving experience.

C. Limitations

Despite its advantages, the system has certain limitations:

- **Limited Driving Range:**

Due to the lower energy density of lead-acid batteries, the vehicle offers a limited range compared to advanced EVs using lithium-ion batteries.

- **Longer Charging Duration:**

Lead-acid batteries require longer charging times (typically 6–8 hours), which may not be suitable for applications requiring quick turnaround.

- **Lower Energy Density:**

The battery pack is relatively heavy and bulky, which affects vehicle efficiency and overall performance.



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- **Reduced Battery Life:**

Frequent deep discharging can reduce the lifespan of lead-acid batteries, necessitating periodic replacement.

D. Discussion

The results indicate that the proposed 60V EV powertrain is well-suited for **low-speed and short-range applications**, where cost and simplicity are key considerations. While the system may not match the performance of high-end EVs, it provides a practical and efficient solution for localized transportation needs.

The performance can be significantly improved by adopting advanced technologies such as lithium-ion batteries, regenerative braking, and intelligent energy management systems. These enhancements can increase driving range, reduce charging time, and improve overall system efficiency.

VII. CONCLUSION

This paper presents the successful design, development, and implementation of a **60V electric vehicle (EV) powertrain system** for a 4-seater electric vehicle intended for low-speed and short-distance applications. The proposed system integrates key components, including a lead-acid battery pack, a 1500W DC motor, a PWM-based motor controller, and an AC-DC charging unit, to achieve a reliable and efficient powertrain architecture.

The experimental results demonstrate that the developed system provides **stable performance, smooth acceleration, and efficient energy utilization** under varying operating conditions. The PWM-based control technique plays a significant role in regulating motor speed and torque, ensuring precise control and reduced energy losses. The vehicle achieves a practical maximum speed of approximately 40 km/h, making it suitable for applications such as campus mobility, industrial transport, and urban short-range commuting.

One of the major strengths of the proposed system is its **cost-effectiveness and simplicity**, achieved through the use of readily available components and a straightforward control strategy. Additionally, the system contributes to environmental sustainability by producing **zero tailpipe emissions**, reducing noise pollution, and minimizing dependence on fossil fuels. The reduced number of mechanical components also leads to **lower maintenance requirements** compared to conventional internal combustion engine vehicles.

However, certain limitations are observed, particularly due to the use of lead-acid batteries, which offer lower energy density, increased weight, and longer charging times. Despite these constraints, the developed powertrain serves as a **practical and scalable solution** for low-cost EV applications.

Overall, the work establishes a strong foundation for further research and development in electric mobility systems. The proposed design demonstrates that an efficient, reliable, and economically viable EV powertrain can be realized using simple technologies, making it a suitable model for future enhancements and real-world implementation.

VIII. FUTURE SCOPE

The proposed 60V electric vehicle (EV) powertrain demonstrates a reliable and cost-effective solution for low-speed mobility applications. However, there are several opportunities for further improvement and technological advancement to enhance performance, efficiency, and user experience.

- **Adoption of Lithium-Ion Battery Systems:**

Replacing the existing lead-acid battery pack with lithium-ion batteries can significantly improve energy density, reduce overall weight, and increase driving range. Lithium-ion batteries also offer faster charging, longer cycle life, and better efficiency, making them more suitable for modern EV applications.

- **Implementation of Fast-Charging Technology:**

Integrating fast-charging systems can drastically reduce charging time, enabling quicker turnaround and improved usability. Advanced charging techniques, such as high-current charging and smart charging algorithms, can be incorporated while ensuring battery safety and longevity.

- **Integration of Solar Charging Systems:**

The addition of solar panels can provide supplementary energy, especially for daytime operation. Solar-assisted



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charging can reduce dependency on grid power and improve overall energy sustainability, particularly in regions with high solar availability.

- **IoT-Based Real-Time Monitoring and Diagnostics:**

Incorporating Internet of Things (IoT) technology can enable real-time monitoring of critical parameters such as battery voltage, current, temperature, and state of charge (SoC). This allows for predictive maintenance, fault detection, remote diagnostics, and improved system reliability through data analytics.

- **Use of BLDC Motor for Higher Efficiency:**

Replacing the conventional DC motor with a Brushless DC (BLDC) motor can enhance efficiency, reduce maintenance, and improve performance due to the absence of brushes. BLDC motors also provide better speed control, higher torque-to-weight ratio, and longer operational life.

- **Regenerative Braking System:**

Future implementations can include regenerative braking to recover kinetic energy during braking and store it back in the battery. This can improve overall energy efficiency and extend the driving range of the vehicle.

- **Advanced Motor Control Techniques:**

Implementation of advanced control methods such as Field-Oriented Control (FOC) or vector control can improve dynamic response, efficiency, and precision in speed and torque control.

- **Battery Management System (BMS):**

Incorporating an intelligent BMS can enhance battery safety and lifespan by monitoring cell voltage, temperature, and balancing charge across cells.

- **Lightweight Vehicle Design:**

Using lightweight materials such as aluminum or composite structures can reduce vehicle weight, thereby improving efficiency and range.

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