

Research Paper**Design and Development of an Intelligent Multi-Utility Electric Vehicle Powertrain System with Smart Energy Management**ALETI LAXMI KANTH¹, G.P.MERLINE²¹Mtech Student, Dept of EEE, Holy Mary Institute of Technology & Science, Keesara, Bogaram, Telangana, India.²Assistant Professor, Dept of EEE, Holy Mary Institute of Technology & Science, Keesara, Bogaram, Telangana, India. Mailid: merline.g@hmgci.ac.in**ABSTRACT:**

Due to the growing demand for sustainable modes of transport, alternative vehicles to the traditional internal combustion engine (ICE) vehicles, such as electric vehicles (EVs) are being developed quickly. But most of the current EVs are designed specifically for transportation use, and they cannot be adapted to a wide range of transportation and industrial applications. This paper discusses the research and development of a Multi-Utility Electric Vehicle (MUEV) Powertrain System that supports a variety of applications using a light-weight and modular design. An improved chassis, motor controller, lithium-ion battery pack, and Permanent Magnet Synchronous Motor (PMSM) are all part of the suggested system, which aims to enhance performance, dependability, and efficiency. The chassis was designed in Autodesk Fusion 360 and tested in ANSYS Workbench for deformation, stress distribution, buckling resistance and crashworthiness for the front impact scenario. A combination of weight optimization techniques allowed the chassis to

retain almost 51% of its weight without compromising on its structure. The Worldwide Harmonized Light Vehicles Test Cycle (WLTC) and SIMCENTER Amesim/MATLAB simulation software were used to analyse the vehicle dynamics, battery State of Charge (SOC), motor efficiency, torque characteristics and driving range. The recommended design was tested for the motor and the controller. The simulation had resulted in efficient running of the motor, the battery had not shown any changes in performance and the torque had been transmitted through the integrated gearbox, with a maximum speed of 32 km/h. It can be easily adapted to other uses, such as passenger carrying, goods transport, industry, and other utilities. In summary, the MUEV power train is an efficient solution, both in terms of weight and cost, that can help to realize sustainable mobility, increase the adaptability of vehicles and facilitate future electric mobility systems.

I INTRODUCTION

The growing urbanization, industrialization and a booming world population have made the demand

for sustainable, reliable and efficient transport systems soar. Previously, transportation was dependent upon using traditional vehicles with internal combustion engines (ICEs). But serious environmental issues like air pollution, greenhouse gas emission, and the depletion of non-renewable energy sources have emerged due to their dependence on fossil fuels. The issues have raised awareness on climate change and energy security, and therefore, researchers, government and auto companies are searching for sustainable solutions. Electric vehicles (EVs) are one of the many possible solutions that are being touted for sustainable transportation, energy efficiency, and reducing carbon emissions. To power their operations, electric cars do not use fossil fuels like gasoline or diesel, but rather electrical energy kept in rechargeable batteries. Higher adoption rate of EVs for transportation has been driven by numerous benefits such as zero tailpipe emissions, lower running costs, reduced maintenance requirements and high energy conversion efficiency. Continual advances in electric motors, charging stations, sophisticated control systems, power electronics and batteries have fueled the prevalence of electric vehicles. Governments around the world are also trying to become carbon neutral by investing in charging stations, offering tax incentives, and financial incentives for EV use.

However, in spite of all these extraordinary advances, the current generation of EVs is mostly designed for specific functions,

including, for example, passenger transport, goods deliveries and transport in industry or for leisure. This design is specific to the application, limiting the flexibility and versatility of EVs in various work environments. Vehicle acquisition costs, maintenance costs, and resource utilization are all negatively impacted when various industries need different vehicles for different jobs. The need for an ever expanding range of electric vehicle platforms is growing because transportation needs are constantly evolving, and they must be used many times without the need to radically change the shape of the vehicles.



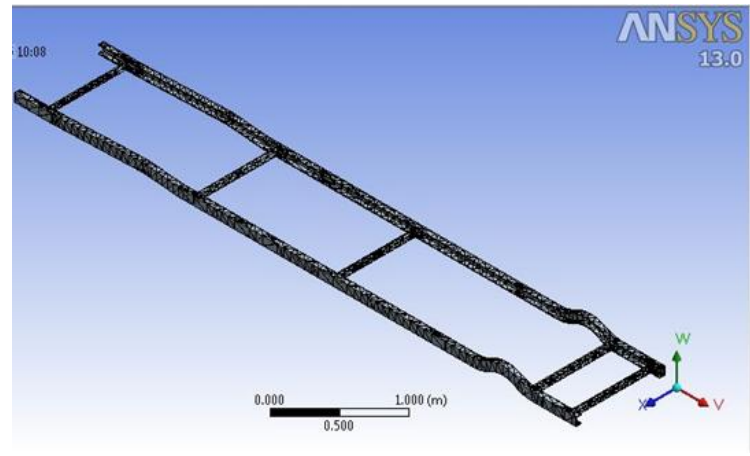
A multi-utility electric vehicle brings together the advances in the fields of intelligent control systems, software engineering, electronics, software engineering and mechanical engineering. The vehicle's dependability, safety, performance, and economy are all improved because to the integration of these interdisciplinary technologies. A MUEV's powertrain consists of several key components such as the battery pack, electric motor, motor controller, gearbox, power electronics, VCU and chassis. Combined, the subsystems significantly improve the efficiency, performance, operating and driving ranges of the vehicle. It is therefore essential to carefully

consider the electrical and mechanical components when developing an optimal powertrain.

The structural design of a vehicle's chassis is a critical part of the vehicle's overall efficiency, safety, and performance. Despite their considerable strength, old steel frame bodies make vehicles heavier, resulting in slower acceleration, faster battery loss and reduced range. So, to keep their structural weight down without sacrificing mechanical strength or crashworthiness, contemporary electric cars are making more and more use of lightweight materials like carbon fiber composites, glass fiber reinforced plastics, and aluminum alloys. Lightweight chassis designs can increase vehicle economy, but without compromising on safety for passengers.

Crashworthiness is a critical factor in designing an electric car. If a collision occurs the chassis must be strong enough to absorb the impact but still retain the integrity of the vehicle to protect the driver and other important components of the engine. The simulation of frontal collisions, stress distribution, deformation, energy absorption and buckling behaviour can be virtually tested by using state-of-the-art finite element analysis (FEA) software like ANSYS Workbench before actual prototypes are produced. These models greatly reduced development time and costs while providing increased structural dependability. To achieve the safest possible performance, engineers

employ crash simulations to help design the location of components, the type of materials, and the chassis.



II SURVEY OF RESEARCH

1. A. Karki, S. Phuyal, D. Tuladhar, S. Basnet, and B. Shrestha (2020)

A. Karki et al. presented a comprehensive review on the status and future prospects of pure Electric Vehicle (EV) powertrain technologies. The authors analyzed various electric drivetrain architectures, including battery electric vehicles, electric motors, battery technologies, power converters, and charging systems. The study highlighted that Permanent Magnet Synchronous Motors (PMSMs) and lithium-ion batteries provide superior efficiency, reliability, and power density compared to conventional alternatives. The paper also discussed optimization techniques for improving driving range, battery lifespan, and energy efficiency through advanced control strategies. Furthermore, the authors reviewed the challenges associated with commercialization, including charging infrastructure, battery cost, thermal management, and material availability. The study emphasized that future EV

development should focus on lightweight materials, high-energy-density batteries, and intelligent energy management systems. Although the review covered numerous aspects of EV technology, it did not specifically address modular or multi-utility vehicle platforms capable of serving multiple applications. Nevertheless, this work provides an excellent foundation for understanding modern EV powertrain technologies and their future research directions. It remains one of the most cited review papers in electric vehicle research and serves as an important reference for designing efficient and sustainable electric powertrain systems.

2. Özgür Üstün, Ramazan Nejat Tuncay, Mert Safa Mökükçü, Ömer Cihan Kıvanç, Gürkan Tosun, Can Gökçe, and Murat Çakan (2018)

Üstün et al. proposed an integrated methodology for the design, analysis, and implementation of an electric vehicle powertrain. Their work focused on developing a compact propulsion system by integrating the electric motor, battery pack, controller, and transmission into a lightweight vehicle architecture. The authors used vehicle dynamics calculations to determine power and torque requirements before designing the propulsion system. Experimental testing validated the proposed powertrain, demonstrating satisfactory acceleration, efficiency, and thermal performance. The study emphasized reducing system weight while maintaining high power density and reliability. It

also discussed the importance of thermal management, compact packaging, and component integration in improving EV performance. Although the proposed design successfully demonstrated a functional electric powertrain, the research primarily concentrated on passenger vehicle applications rather than adaptable multi-purpose platforms. The work significantly contributes to the understanding of integrated EV powertrain development and provides valuable guidelines for future electric vehicle designers aiming to achieve high efficiency, compactness, and improved energy utilization.

3. Manimaran Saravanan, Bharatiraja Chokkalingam, Rajesh Verma, Shubhabrata Datta, and Lucian Mihet-Popa (2026)

Saravanan et al. developed a Multi-Utility Electric Vehicle (MUEV) powertrain system designed to support multiple transportation applications using a modular vehicle architecture. The research integrated a Permanent Magnet Synchronous Motor (PMSM), lithium-ion battery, optimized chassis, and intelligent control system to improve overall vehicle performance. Structural analysis was performed using ANSYS Workbench to evaluate crashworthiness, deformation, stress distribution, and energy absorption, while SIMCENTER Amesim was used to simulate battery performance, motor efficiency, torque characteristics, and driving range. The study achieved approximately 51% chassis weight reduction while maintaining structural integrity and demonstrated a maximum

vehicle speed of 32 km/h. The modular design allows the vehicle to be adapted for passenger transport, cargo delivery, industrial services, and commercial applications with minimal modifications. The research concluded that lightweight construction and optimized powertrain integration significantly improve energy efficiency and operational flexibility. This study provides an important contribution toward sustainable transportation by demonstrating the feasibility of modular electric vehicle platforms for diverse utility applications.

4. Md. Mosleuzzaman, Md. Delwar Hussain, H. M. Shamsuzzaman, Arif Mia, and Shakhawat Hossain (2024)

Mosleuzzaman et al. reviewed recent innovations in electric vehicle powertrain design with particular emphasis on electrical engineering advancements. Their study discussed developments in electric motors, battery technologies, power electronics, thermal management, and regenerative braking systems. The authors highlighted the increasing use of wide-bandgap semiconductor devices such as Silicon Carbide (SiC) and Gallium Nitride (GaN), which significantly improve inverter efficiency while reducing switching losses. The review also emphasized modular powertrain architectures and artificial intelligence-based control strategies for improving vehicle performance and adaptability. Battery management systems, solid-state batteries, and advanced cooling methods were identified as key

technologies for future EV development. The paper concluded that integrating intelligent control algorithms with modular powertrain architectures would significantly enhance efficiency, reliability, and sustainability. Although the study primarily reviewed existing technologies rather than proposing a new design, it provides valuable insights into emerging trends that can be incorporated into next-generation multi-utility electric vehicles.

5. M. M. H. Mia (2025)

Mia presented a review of technological developments in electric vehicle powertrain and battery systems. The study discussed rapid improvements in electric motors, battery chemistry, energy management, and charging technologies. Particular attention was given to lithium-ion batteries, battery management systems, regenerative braking, and advanced power electronics. The review explained how improvements in battery energy density and motor efficiency contribute to increased vehicle driving range while reducing charging time. The author also emphasized the importance of intelligent control systems for optimizing battery usage and extending battery life. Furthermore, the study examined future developments including solid-state batteries, wireless charging, and smart energy management. Although the review focused mainly on technological advancements rather than specific vehicle platforms, it highlighted the importance of integrating multiple technologies into efficient electric powertrain

systems. The paper serves as a valuable reference for researchers developing next-generation electric vehicles with improved efficiency, reliability, and sustainability.

6. Laurence W. Davis (2023)

Laurence W. Davis investigated the role of electric vehicles within multi-vehicle households and analyzed consumer adoption patterns. The research examined how electric vehicles are utilized alongside conventional vehicles and identified driving range limitations, charging infrastructure, and travel behavior as major factors influencing adoption. The study concluded that improving battery capacity and charging accessibility would significantly increase EV usage for diverse transportation needs. Davis also emphasized that flexible vehicle platforms capable of serving multiple purposes could improve utilization rates and reduce ownership costs. Although the research primarily focused on consumer behavior rather than engineering design, its findings highlight the growing need for adaptable electric vehicle architectures capable of replacing multiple conventional vehicles. The study provides useful insights into the practical requirements of future multi-utility electric vehicles and their potential impact on sustainable transportation systems.

7. Zongtan Li and Yunli Shao (2024)

Li and Shao proposed a co-optimization strategy for vehicle dynamics and electric powertrain management in connected and

automated electric vehicles. Their research developed mathematical models for vehicle dynamics, battery behavior, and dual-motor powertrain systems using optimal control techniques. Simulation results demonstrated significant reductions in energy consumption while maintaining acceptable vehicle performance under varying traffic conditions. The proposed strategy optimized torque distribution and vehicle speed simultaneously, resulting in energy savings of more than 12%. The study concluded that intelligent control algorithms can substantially improve electric vehicle efficiency by coordinating powertrain operation with driving conditions. Although the research focused on automated electric vehicles, its optimization techniques can be applied to multi-utility electric vehicles to improve energy efficiency, battery utilization, and driving performance.

8. G. Jenner De Faria Orsi (2024)

Orsi investigated model predictive control techniques for electric vehicle powertrain optimization. The study developed mathematical models describing battery dynamics, electric motor performance, inverter behavior, and drivetrain characteristics. Model Predictive Control (MPC) was implemented to minimize energy consumption while maintaining desired vehicle speed and acceleration. Simulation results demonstrated improved battery efficiency, smoother torque delivery, and reduced energy losses under varying driving conditions. The research highlighted the importance of predictive

energy management strategies in extending driving range and improving vehicle reliability. Although experimental validation was limited, the proposed control methodology provides a strong foundation for future intelligent powertrain systems used in multi-utility electric vehicles.

9. I. Pavić, H. Pandžić, and T. Capuder (2019)

Pavić et al. introduced the concept of an EV-based smart e-mobility system in which electric vehicles function as dynamic mobile energy storage units. The study proposed a framework that enables electric vehicles to interact with multiple charging stations while optimizing charging schedules and energy utilization. The authors demonstrated that treating EVs as mobile storage devices improves grid flexibility and renewable energy integration. The research emphasized intelligent charging management, communication systems, and smart grid coordination. Although the work focused on charging infrastructure rather than vehicle design, it highlights future opportunities for integrating multi-utility electric vehicles into intelligent transportation and energy systems.

10. Eymen Ipek and Mario Hirz (2025)

Ipek and Hirz proposed a data-driven framework for electric vehicle powertrain modeling to accelerate system development and virtual validation. Their methodology integrated battery, inverter, electric motor, and control models using standardized interfaces that enable

modular system development. The study demonstrated that combining physics-based and data-driven models significantly reduces development time while maintaining high prediction accuracy. The authors concluded that modular simulation frameworks are highly suitable for modern electric vehicle development because they support rapid testing of different powertrain configurations without extensive physical prototyping. This approach is particularly beneficial for designing multi-utility electric vehicles where multiple configurations and operating conditions must be evaluated efficiently before prototype construction.

WORKING METHODOLOGY

The proposed Multi-Utility Electric Vehicle (MUEV) Powertrain System is developed through a systematic methodology that integrates mechanical design, electrical engineering, simulation, and experimental validation to achieve a lightweight, energy-efficient, and versatile electric vehicle platform. Initially, the design requirements are identified based on the intended applications, such as passenger transportation, cargo delivery, industrial services, and commercial utility. Parameters including vehicle dimensions, payload capacity, maximum speed, driving range, battery capacity, and motor power are determined to meet operational requirements. Based on these specifications, the major components of the electric powertrain including the Permanent Magnet Synchronous Motor (PMSM), lithium-ion battery pack, motor controller, battery management system (BMS),

vehicle control unit (VCU), gearbox, differential, and chassis—are carefully selected. The PMSM is chosen due to its high efficiency, excellent torque characteristics, compact size, and reliability, while lithium-ion batteries provide high energy density, long service life, and fast charging capability. The Battery Management System continuously monitors battery voltage, current, temperature, State of Charge (SOC), and State of Health (SOH) to ensure safe operation and maximize battery life. Simultaneously, the Vehicle Control Unit coordinates communication between the battery, motor, controller, and other electrical subsystems, enabling smooth vehicle operation and efficient energy utilization. This systematic selection of components establishes a strong foundation for developing a modular and high-performance electric vehicle capable of supporting multiple applications with improved reliability and reduced operating costs.

Following component selection, the mechanical design of the vehicle is carried out using Autodesk Fusion 360, where a complete three-dimensional model of the chassis and powertrain layout is created. The chassis is designed with a modular architecture to support different superstructures, allowing the same vehicle platform to be adapted for various applications without major structural modifications. Weight optimization is an essential part of this stage, where unnecessary structural members are removed and lightweight materials such as aluminum alloys, carbon fiber

composites, and glass fiber composites are considered to reduce the overall vehicle weight while maintaining sufficient structural strength. Proper placement of the battery pack, electric motor, controller, steering mechanism, and suspension system is carefully planned to achieve balanced weight distribution and a lower center of gravity, thereby improving vehicle stability and handling. The CAD model also incorporates sufficient space for maintenance, battery replacement, cooling systems, and electrical wiring. Design constraints such as wheelbase, ground clearance, turning radius, suspension travel, and load distribution are considered throughout the modeling process to ensure that the vehicle satisfies practical operational requirements. The completed CAD model serves as the basis for further structural analysis and powertrain integration, ensuring that both mechanical and electrical systems are efficiently accommodated within the vehicle architecture.

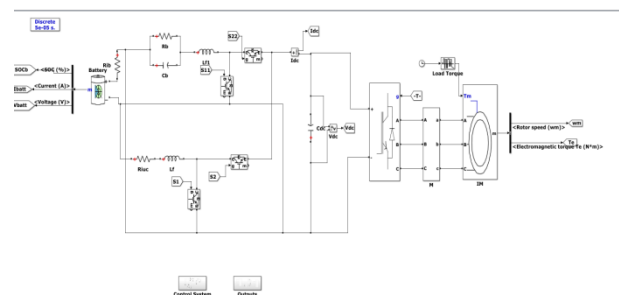


Fig.1 simulation model

The structural performance of the designed chassis is evaluated using ANSYS Mechanical Workbench through Finite Element Analysis (FEA). Various analyses are performed to validate the safety and durability of the vehicle under different operating conditions. Frontal

crash analysis evaluates deformation, von-Mises stress, strain distribution, and energy absorption when the chassis experiences collision impact, ensuring passenger protection and structural integrity. Static structural analysis examines the chassis under the combined loads of passengers, batteries, motor, and cargo to determine maximum deformation and structural stability during normal operation. Buckling analysis is performed to identify the critical load conditions that may cause structural instability, while composite material analysis compares aluminum alloy, carbon fiber, and glass fiber composites based on strength, weight, deformation, and stress characteristics to identify the most suitable chassis material. Simultaneously, the electrical powertrain is simulated using SIMCENTER Amesim and MATLAB/Simulink, where the performance of the PMSM motor, lithium-ion battery, gearbox, and controller is analyzed under the Worldwide Harmonized Light Vehicle Test Cycle (WLTC). The simulation evaluates motor speed, torque, efficiency, battery State of Charge (SOC), Depth of Discharge (DOD), energy consumption, driving range, and vehicle dynamics under realistic driving conditions. Environmental factors such as rolling resistance, air density, wind speed, and road conditions are also incorporated into the simulation to obtain accurate predictions of vehicle performance.

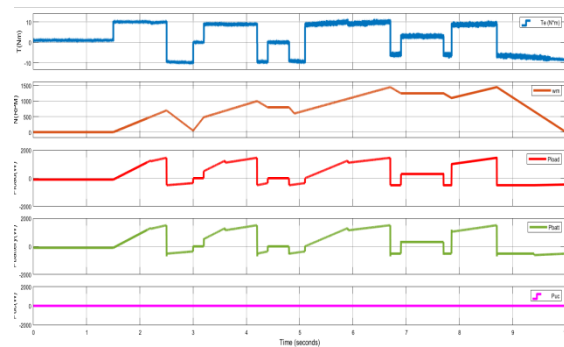


Fig.2. Output of DC motor

After successful simulation, the proposed powertrain system is experimentally validated through laboratory testing. The PMSM motor is connected to its motor controller, battery pack, throttle, and external power supply to verify motor performance under practical operating conditions. Electrical parameters such as voltage, current, power, motor speed, torque, controller efficiency, and battery behavior are continuously monitored using measuring instruments including oscilloscopes, multimeters, and current sensors. The gearbox performance is analyzed by comparing motor speed and torque before and after gear reduction, demonstrating the effectiveness of torque multiplication for improved vehicle acceleration and load-carrying capability. Battery performance is evaluated throughout charging and discharging cycles by monitoring State of Charge, battery voltage, current, and temperature to ensure safe and efficient energy utilization. The Battery Management System protects the battery from overcharging, excessive discharge, and thermal overload while maintaining optimal operating conditions. These experimental results are compared with simulation outputs to verify the

accuracy of the developed models and identify any deviations requiring further optimization. The validation process confirms that the selected powertrain components operate efficiently as an integrated system and satisfy the intended vehicle performance requirements.

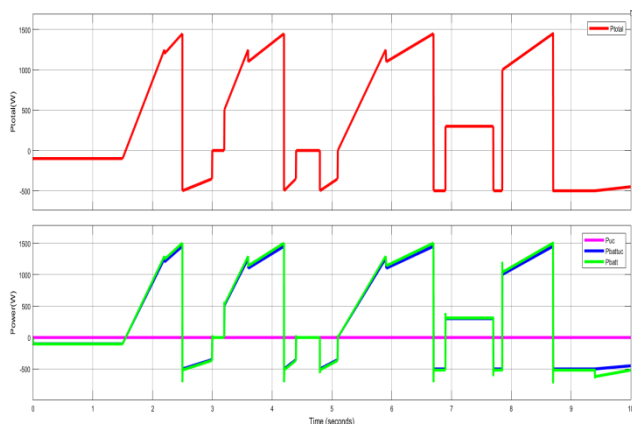


Fig.2. Power output motor and battery

Finally, the optimized chassis and validated powertrain components are assembled to develop the complete Multi-Utility Electric Vehicle prototype. The prototype undergoes comprehensive testing, including static inspection, dynamic road testing, load testing, braking performance, steering evaluation, acceleration testing, and battery endurance analysis under different operating conditions. Experimental observations are compared with simulation results to evaluate parameters such as vehicle speed, driving range, motor efficiency, battery utilization, energy consumption, structural safety, and overall system reliability. Based on the obtained results, necessary improvements are incorporated by optimizing the controller algorithm, reducing structural weight, improving battery utilization, and enhancing powertrain efficiency. The modular

design enables the vehicle to be easily converted into passenger, cargo, industrial, or commercial utility configurations by modifying only the upper body while retaining the same chassis and powertrain architecture. This integrated methodology demonstrates that combining advanced computer-aided design, finite element structural analysis, intelligent powertrain simulation, and experimental validation results in a lightweight, energy-efficient, reliable, and sustainable Multi-Utility Electric Vehicle capable of meeting the diverse transportation needs of future smart mobility systems.

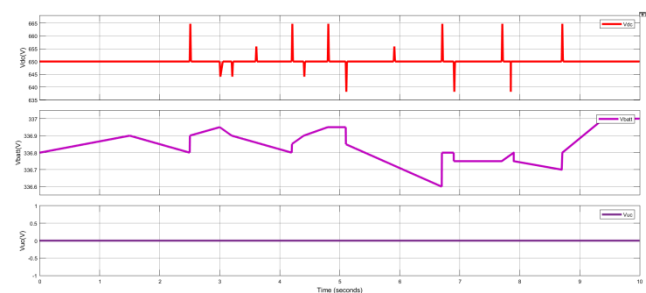


Fig.3. Battery and DC link capacitor results

CONCLUSION

The Multi-Utility Electric Vehicle (MUEV) Powertrain System presented in this study demonstrates an effective approach toward developing a lightweight, energy-efficient, and versatile electric vehicle capable of supporting multiple transportation applications. By integrating a Permanent Magnet Synchronous Motor (PMSM), lithium-ion battery pack, advanced motor controller, optimized chassis, and intelligent control system, the proposed powertrain achieves improved performance, reliability, and operational flexibility. The use of lightweight materials and structural optimization

significantly reduces vehicle weight while maintaining structural strength and crash safety. Comprehensive structural analyses using ANSYS Workbench confirmed the chassis' ability to withstand frontal impact, static loading, and buckling conditions, whereas simulations using SIMCENTER Amesim and MATLAB validated the efficiency of the motor, battery, and drivetrain under realistic driving conditions. Experimental testing further verified the accuracy of the simulation results and demonstrated stable battery performance, efficient torque delivery, and reliable vehicle operation. The modular architecture enables the vehicle to be easily adapted for passenger transport, cargo movement, industrial services, and commercial applications, reducing manufacturing and operational costs. Overall, the proposed MUEV powertrain contributes to sustainable transportation by improving energy utilization, reducing environmental impact, and enhancing vehicle adaptability. The developed methodology provides a strong foundation for future research on intelligent electric vehicle platforms, advanced battery technologies, autonomous driving systems, and smart energy management, supporting the continued evolution of next-generation electric mobility solutions.

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