A Peer Study on Powertrain Topologies in Electric Vehicles and Hybrid Electric Vehicles

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Abstract: The rapid evolution of the global transportation sector has intensified the demand for energy-efficient, environmentally friendly, and technologically advanced mobility solutions. Conventional internal combustion engine (ICE) vehicles have long dominated the automotive industry; however, their dependence on fossil fuels, increasing greenhouse gas emissions, and declining fuel reserves have accelerated the transition toward electrified transportation systems. Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) have emerged as promising alternatives that can significantly reduce emissions, improve energy efficiency, and enhance overall vehicle performance. A critical component that determines the performance, efficiency, and operational flexibility of these vehicles is the powertrain topology, which defines how various energy sources, electric motors, power electronics, and energy storage systems interact to deliver propulsion. This study presents a comprehensive peer study on different powertrain topologies used in EVs and HEVs, focusing on their structural configurations, operating principles, advantages, and limitations. The research examines major architectures including series hybrid, parallel hybrid, series–parallel hybrid, and fully electric powertrain systems. The study also evaluates the role of key subsystems such as electric motors, battery packs, power converters, and energy management strategies in influencing vehicle efficiency and driving performance. By comparing these topologies from the perspectives of energy utilization, complexity, cost, and scalability, the paper highlights the most suitable configurations for various transportation requirements ranging from urban commuting to long-distance travel. Furthermore, the analysis emphasizes the technological advancements in battery technology, regenerative braking, and intelligent power management that enhance the effectiveness of modern EV and HEV systems. The findings of this peer study provide valuable insights into the design considerations and performance trade-offs associated with different powertrain architectures. Ultimately, the research contributes to a deeper understanding of how optimized powertrain topologies can support the development of sustainable, efficient, and reliable next-generation electric mobility solutions.

Keywords: *Electric Vehicle, Hybrid Electric Vehicle, Electric Vehicle Powertrain, Energy Storage Systems, Vehicle Dynamics*

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I. INTRODUCTION

The global transportation sector has experienced tremendous growth over the past century, becoming one of the most essential components of modern economic and social development[1]. Road transportation in particular plays a critical role in enabling mobility, facilitating trade, and supporting industrial expansion across nations. For decades, conventional vehicles powered by internal combustion engines (ICEs) have dominated the automotive industry due to their established technology, widespread fueling infrastructure, and relatively low manufacturing costs. However, the extensive reliance on fossil fuels such as petrol and diesel has raised significant environmental, economic, and sustainability concerns[2]. Increasing fuel consumption, rising greenhouse gas emissions, and growing urban pollution levels have motivated researchers, policymakers, and automotive manufacturers to explore alternative propulsion technologies that can reduce the environmental footprint of transportation systems while maintaining efficiency and reliability[3].

One of the most pressing challenges associated with traditional ICE vehicles is the emission of harmful pollutants including carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons, and particulate matter. These emissions contribute significantly to global climate change, air pollution, and various health hazards in urban environments[4]. The rapid growth of vehicle populations across developing and developed nations has intensified these issues, making transportation one of the major contributors to global carbon emissions. In addition to environmental concerns, the volatility of fossil fuel prices and the gradual depletion of petroleum resources have created uncertainty regarding the long-term sustainability of conventional automotive technologies[5]. As a result, governments around the world have begun implementing stricter emission regulations, fuel efficiency standards, and incentives for cleaner transportation technologies[6].

In response to these challenges, electrified vehicle technologies have emerged as promising alternatives capable of transforming the transportation landscape. Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) represent two major categories of electrified transportation systems that integrate electric propulsion technologies with advanced energy storage systems[7]. EVs rely entirely on electric motors powered by rechargeable batteries, eliminating the need for internal combustion engines and significantly reducing tailpipe emissions. HEVs, on the other hand, combine conventional internal combustion engines with electric motors and battery systems to achieve improved fuel efficiency and reduced emissions compared to traditional vehicles. These vehicles utilize advanced power electronic converters, energy management systems, and regenerative braking technologies to optimize energy utilization and enhance driving performance[8].

A crucial component that determines the performance, efficiency, and operational characteristics of EVs and HEVs is the powertrain system. The powertrain consists of several interconnected subsystems including the energy source, electric motor, transmission system, power electronics, and energy management controller. The configuration and interaction of these components define the powertrain topology of the vehicle. Different powertrain topologies influence various factors such as energy efficiency, acceleration capability, fuel consumption, system complexity, and overall cost of the vehicle. As a result, selecting an appropriate powertrain architecture is a key design consideration in the development of modern electrified vehicles[9].

Over the years, researchers and automotive manufacturers have proposed multiple powertrain topologies for EVs and HEVs to address different operational requirements and performance objectives. In hybrid electric vehicles, the most widely studied configurations include series hybrid, parallel hybrid, and series–parallel hybrid architectures. In the series hybrid topology, the internal combustion engine is not directly connected to the wheels but instead drives an electric generator that supplies power to the electric motor or charges the battery[10]. This configuration allows the engine to operate at optimal efficiency but may introduce additional energy conversion losses. In contrast, the parallel hybrid topology allows both the engine and the electric motor to provide mechanical power directly to the wheels, improving efficiency and reducing energy conversion losses. The series–parallel hybrid topology combines the advantages of both configurations, offering greater flexibility in power distribution and improved overall efficiency[11].

In the case of fully electric vehicles, several powertrain architectures have also been developed to optimize performance and energy utilization. These include single motor drive systems, dual motor configurations, and multi-motor distributed drive systems. Single motor EV powertrains are relatively simple and cost-effective, making them suitable for many passenger vehicle applications[12]. Dual motor configurations enable improved traction control and performance by distributing power between the front and rear axles. Distributed drive systems, which utilize multiple in-wheel motors, offer enhanced vehicle dynamics, improved energy efficiency, and greater design flexibility, although they introduce additional complexity in control and integration[13].

Despite the rapid advancements in EV and HEV technologies, several technical and research challenges remain in the design and optimization of powertrain systems. One of the key research gaps lies in the comprehensive comparative analysis of different powertrain topologies under varying operational conditions. While many studies have focused on individual architectures, fewer studies have conducted systematic peer comparisons that evaluate the advantages, limitations, and performance trade-offs of multiple topologies simultaneously. Such comparative studies are essential for identifying optimal configurations for different vehicle categories, driving patterns, and application environments[14].

Another important research gap relates to energy management strategies within hybrid and electric powertrains. Efficient coordination between multiple energy sources such as internal combustion engines, batteries, and regenerative braking systems is necessary to achieve optimal performance and fuel efficiency. The development of intelligent control algorithms and advanced power management techniques remains an active area of research aimed at maximizing energy utilization while minimizing losses and system complexity[15].

Battery technology also plays a crucial role in the effectiveness of electric vehicle powertrains. Although significant progress has been made in improving battery energy density, charging speed, and lifecycle performance, challenges related to battery cost, thermal management, and charging infrastructure continue to affect the widespread adoption of EVs. Furthermore, the integration of battery systems with power electronic converters and motor drive systems requires careful design to ensure safe and efficient operation under varying load conditions[16].

In addition to technical challenges, economic and infrastructural factors influence the adoption of EV and HEV technologies. The availability of charging infrastructure, battery recycling processes, and grid integration mechanisms are important considerations for the large-scale deployment of electric mobility solutions. Governments and industry stakeholders are actively working toward addressing these issues through policy incentives, technological innovation, and investments in charging networks[17].

Despite these challenges, the benefits of EVs and HEVs have become increasingly evident in recent years. One of the most significant advantages of electric vehicles is the elimination of tailpipe emissions, which contributes to improved air quality and reduced environmental impact. Electric propulsion systems also offer higher energy conversion efficiency compared to internal combustion engines, resulting in better energy utilization and lower operational costs. Additionally, electric motors provide instant torque, enabling smoother acceleration and improved driving performance[18].

Hybrid electric vehicles provide a practical transitional solution between conventional and fully electric transportation systems. By combining the strengths of internal combustion engines and electric motors, HEVs can achieve significant improvements in fuel efficiency while maintaining the driving range and refueling convenience associated with traditional vehicles. Regenerative braking systems in hybrid vehicles capture kinetic energy during braking and convert it into electrical energy that can be stored in the battery, further enhancing energy efficiency[19].

Another notable advantage of electrified powertrains is their compatibility with renewable energy sources. As electrical grids increasingly incorporate renewable energy technologies such as solar and wind power, EVs have the potential to operate with significantly lower lifecycle emissions compared to fossil-fuel-based transportation systems. This synergy between renewable energy and electric mobility supports global efforts to achieve sustainable energy and environmental goals[20].

Furthermore, advancements in power electronics, electric motor design, and battery management systems have significantly improved the performance, reliability, and efficiency of EV and HEV powertrains. Modern vehicles incorporate sophisticated control algorithms that enable optimal power distribution between different components, ensuring efficient operation under diverse driving conditions. These technological developments continue to accelerate the transition toward electrified transportation systems[21].

Given the growing importance of electric mobility and the diversity of available powertrain architectures, there is a strong need for systematic studies that evaluate the characteristics and performance of various powertrain topologies. Understanding the advantages and limitations of each configuration can help researchers, engineers, and automotive designers make informed decisions when developing next-generation vehicles. Comparative studies also provide valuable insights into how different architectures can be optimized for specific applications such as passenger vehicles, commercial transportation, and urban mobility solutions[22].

Therefore, this study presents a detailed peer analysis of powertrain topologies used in electric vehicles and hybrid electric vehicles. The research focuses on examining the structural configurations, operational principles, and performance characteristics of major powertrain architectures. By analyzing these systems from the perspectives of efficiency, complexity, energy management, and practical implementation, the study aims to identify key design considerations and highlight potential opportunities for further improvement[23].

II. PROPOSED METHODOLOGY

The objective of this study is to perform a systematic peer analysis of different powertrain topologies used in Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs). The methodology focuses on identifying the structural configurations, energy flow mechanisms, and operational characteristics of major powertrain architectures and comparing their performance with respect to efficiency, complexity, energy utilization, and suitability for different transportation requirements. The research methodology is structured into multiple stages including literature review, classification of powertrain topologies, modeling of system components, energy flow analysis, and comparative evaluation**.**

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A. Literature Review and Technology Survey

The first step in the proposed methodology involves a comprehensive review of existing research studies, technical reports, and automotive industry publications related to EV and HEV powertrain technologies. This review helps identify the major powertrain architectures currently used in modern vehicles and highlights their design characteristics, advantages, and limitations.

➢ *Evolution of Electric and Hybrid Vehicle Technologies*

The concept of electric vehicles is not a recent technological development but dates back to the late nineteenth century when early battery-powered vehicles were introduced as alternatives to steam and gasoline-powered automobiles. Early electric vehicles were favored for their quiet operation, ease of control, and absence of exhaust emissions. However, the limited energy density of early battery technologies and the rapid advancement of internal combustion engine (ICE) vehicles resulted in the decline of electric vehicles during the early twentieth century. For many decades, ICE vehicles remained the dominant transportation technology due to their higher

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driving range, faster refueling capabilities, and well-established fuel infrastructure.

Interest in electric mobility began to re-emerge in the late twentieth century due to growing environmental concerns and increasing awareness of fossil fuel depletion. Governments and researchers started exploring cleaner transportation technologies to reduce greenhouse gas emissions and improve air quality in urban environments. This renewed focus led to the development of hybrid electric vehicles, which combine internal combustion engines with electric propulsion systems. Hybrid vehicles provided an intermediate solution that improved fuel efficiency while maintaining the driving range and convenience associated with conventional vehicles.

Over the past two decades, rapid advancements in battery technologies, power electronics, and electric motor design have significantly accelerated the development of electric vehicles. Modern EVs are capable of achieving longer driving ranges, faster acceleration, and improved energy efficiency compared to earlier electric vehicle designs. Automotive manufacturers and research institutions continue to develop new powertrain architectures that optimize energy utilization and vehicle performance. Despite these technological improvements, several challenges remain in terms of cost, infrastructure development, and optimal powertrain configuration.

➢ *Development of Electric Motor Drive Systems*

Electric motors serve as the primary propulsion mechanism in electric vehicles and play a critical role in determining vehicle performance and efficiency. Various types of electric motors have been explored in EV and HEV applications, each offering distinct advantages and limitations. The most commonly used motor technologies include permanent magnet synchronous motors, induction motors, and brushless DC motors.

Permanent magnet synchronous motors (PMSMs) are widely used in modern electric vehicles due to their high efficiency, compact size, and superior torque density. These motors utilize permanent magnets embedded in the rotor to generate a magnetic field, enabling efficient energy conversion and improved dynamic performance. PMSMs are particularly suitable for applications requiring high power density and precise speed control.

Induction motors have also been widely adopted in electric vehicle applications due to their rugged construction, reliability, and relatively low manufacturing cost. Unlike permanent magnet motors, induction motors do not require rare-earth magnets, making them less dependent on expensive materials. However, induction motors generally exhibit slightly lower efficiency compared to PMSMs and may require more complex control strategies.

Brushless DC motors offer advantages such as high efficiency, low maintenance requirements, and good torque characteristics. These motors are commonly used in smaller electric vehicles and light transportation applications. Advances in motor control algorithms and power electronics have significantly improved the performance of these motors in modern electric propulsion systems.

Although significant progress has been made in electric motor technology, research continues to focus on improving motor efficiency, reducing weight, and enhancing thermal management. The integration of advanced motor control techniques and optimization of motor design parameters remain important research areas in the development of high-performance electric vehicle powertrains.

➢ *Advances in Battery Energy Storage Technologies*

Battery technology is one of the most critical components influencing the performance and adoption of electric vehicles. The energy density, charging time, lifespan, and cost of battery systems directly affect the driving range and economic feasibility of EVs. Over the years, several battery technologies have been explored for electric vehicle applications, including lead-acid batteries, nickel-metal hydride batteries, and lithium-ion batteries.

Early electric vehicles relied primarily on lead-acid batteries due to their low cost and established manufacturing processes. However, the relatively low energy density and limited cycle life of these batteries restricted their suitability for long-range electric vehicles. Nickel-metal hydride batteries were later introduced as an improvement over lead-acid batteries and were widely used in early hybrid electric vehicles. These batteries provided better energy density and longer lifespan but were still limited in terms of weight and charging performance.

Lithium-ion battery technology has emerged as the dominant energy storage solution for modern electric vehicles due to its high energy density, lightweight structure, and improved charging efficiency. Lithium-ion batteries enable electric vehicles to achieve significantly longer driving ranges while maintaining compact battery pack designs. Furthermore, ongoing research in battery materials and cell design continues to improve battery performance, safety, and lifespan.

Despite these advancements, several challenges remain in the development of battery systems for electric vehicles. Issues related to battery cost, thermal management, degradation over time, and recycling processes require further investigation. Researchers are also exploring next-generation battery technologies such as solid-state batteries, which promise higher energy density and improved safety characteristics compared to conventional lithium-ion batteries.

➢ *Role of Power Electronic Converters in Electric Vehicles*

Power electronic converters play a vital role in controlling and managing energy flow within electric and hybrid vehicle powertrains. These converters enable efficient conversion of electrical energy between different voltage levels and facilitate the operation of electric motor drives. The primary power electronic components used in

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EV and HEV systems include inverters, DC–DC converters, and onboard battery chargers.

Inverters are responsible for converting direct current (DC) from the battery into alternating current (AC) required by electric motors. Advanced inverter designs incorporate high-efficiency semiconductor devices and sophisticated control algorithms to ensure smooth motor operation and minimize power losses. The efficiency and reliability of the inverter significantly influence the overall performance of the vehicle.

DC–DC converters are used to regulate voltage levels within the vehicle electrical system. These converters allow the high-voltage battery pack to supply power to low-voltage auxiliary systems such as lighting, infotainment, and control electronics. Efficient DC–DC converter design is essential to reduce energy losses and maintain stable voltage levels across different subsystems.

Another important function of power electronics in electric vehicles is the management of regenerative braking systems. During braking, the electric motor operates as a generator, converting kinetic energy into electrical energy that can be stored in the battery. This process improves energy efficiency and extends the driving range of electric vehicles.

Continuous research in power semiconductor technologies, such as silicon carbide (SiC) and gallium nitride (GaN) devices, has led to significant improvements in the efficiency and power density of power electronic converters. These advanced semiconductor materials enable higher switching frequencies, reduced energy losses, and improved thermal performance in electric vehicle powertrain systems.

➢ *Energy Management Strategies in Hybrid Powertrains*

Energy management is a critical aspect of hybrid electric vehicle operation, as it determines how power is distributed between the internal combustion engine, electric motor, and battery system. Efficient energy management strategies are essential for optimizing fuel efficiency, reducing emissions, and maintaining battery health.

Several energy management approaches have been proposed in the literature, including rule-based control strategies, optimization-based control methods, and intelligent control algorithms. Rule-based control strategies rely on predefined operating conditions to determine when the electric motor or engine should be used. These strategies are relatively simple to implement but may not always achieve optimal energy efficiency under varying driving conditions.

Optimization-based control strategies use mathematical models to determine the optimal power distribution between different energy sources. These methods aim to minimize fuel consumption while maintaining vehicle performance requirements. Although optimization-based methods can achieve improved efficiency, they often require significant computational resources and accurate system modeling.

More recently, researchers have explored the use of artificial intelligence techniques such as machine learning and neural networks to develop adaptive energy management systems. These intelligent systems can analyze driving patterns and environmental conditions to optimize power distribution in real time. Such approaches offer promising opportunities for improving the efficiency and performance of hybrid electric vehicles.

Despite the progress made in energy management strategies, there is still a need for improved control algorithms that can effectively handle complex powertrain architectures and dynamic driving conditions. The integration of advanced control methods with modern powertrain designs remains an important area of ongoing research.

➢ *Research Gaps Identified in Existing Studies*

Although extensive research has been conducted on electric and hybrid vehicle technologies, several gaps remain in the comparative evaluation of powertrain architectures. Many existing studies focus on individual components such as motors, batteries, or converters without considering the overall interaction between these subsystems within different powertrain configurations.

Another limitation of current research is the lack of comprehensive peer studies that simultaneously evaluate multiple powertrain topologies using consistent performance parameters. Such comparative studies are essential for identifying the most suitable architectures for different vehicle applications and operational environments.

Additionally, the rapid evolution of electric vehicle technologies requires continuous evaluation of emerging powertrain designs, advanced battery systems, and intelligent energy management strategies. Addressing these research gaps can contribute to the development of more efficient, reliable, and sustainable electric mobility solutions.

B. Classification of Powertrain Topologies

The methodology involves categorizing the different powertrain architectures used in EVs and HEVs. These topologies are broadly classified into two major groups:

➢ *Electric Vehicle Powertrain Topologies*

Electric vehicles operate entirely using electric propulsion systems. The main powertrain configurations analyzed in this study include:

- Single Motor Electric Drive
- Dual Motor Electric Drive
- Distributed In-Wheel Motor Drive

These configurations differ in terms of motor placement, power distribution, and control strategies.

➢ *Hybrid Electric Vehicle Powertrain Topologies*

Hybrid electric vehicles combine internal combustion engines with electric propulsion systems. The commonly used hybrid configurations include:

- Series Hybrid Powertrain
- Parallel Hybrid Powertrain
- Series–Parallel Hybrid Powertrain

Each topology offers unique advantages in terms of fuel efficiency, performance, and system complexity.

C. System Modeling of EV and HEV Powertrain Components

To evaluate the characteristics of each topology, the proposed methodology models the major subsystems involved in EV and HEV powertrains. The following key components are considered:

➢ *Battery Energy Storage System:*

The battery pack serves as the primary energy source for electric propulsion systems. Lithium-ion batteries are widely used due to their high energy density, long cycle life, and improved efficiency. The battery model in this study considers parameters such as voltage level, capacity, charging characteristics, and energy discharge rate.

➢ *Electric Motor Drive System:*

Electric motors convert electrical energy into mechanical torque for vehicle propulsion. Commonly used motor types include:

- Permanent Magnet Synchronous Motors (PMSM)
- Induction Motors (IM)
- Brushless DC Motors (BLDC)

Motor performance is analyzed based on torque characteristics, efficiency, power density, and control complexity.

➢ *Power Electronic Converters:*

Power electronic converters regulate energy flow between the battery, electric motor, and auxiliary systems. The primary converters used in EV powertrains include:

- DC–DC converters
- Inverters
- Motor drive controllers

These converters ensure efficient power conversion and enable variable speed motor control.

➢ *Internal Combustion Engine (for HEVs):*

In hybrid electric vehicles, the internal combustion engine acts as a secondary power source. The engine provides mechanical power either directly to the wheels or indirectly through a generator depending on the hybrid topology.

➢ *Energy Management System:*

The energy management controller coordinates the operation of different power sources and optimizes energy utilization under varying driving conditions. It determines the power distribution between the battery and engine to achieve optimal efficiency.

D. Power Flow Analysis in EV Powertrain

The next stage of the methodology focuses on analyzing energy flow within different EV powertrain configurations.

➢ *Single Motor Electric Vehicle Architecture*

In the single motor configuration, a single electric motor drives the vehicle through a transmission system. Electrical energy stored in the battery is converted into mechanical energy by the motor through an inverter.

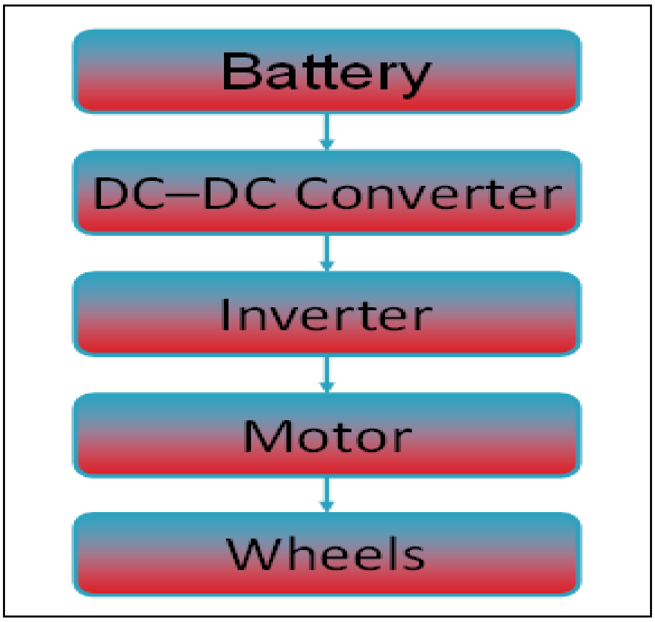

Fig 1 Single Motor Electric Vehicle Powertrain

➢ *Dual Motor Electric Vehicle Architecture*

Dual motor EVs utilize two independent motors placed on the front and rear axles. This configuration improves traction control and vehicle performance by enabling independent torque distribution.

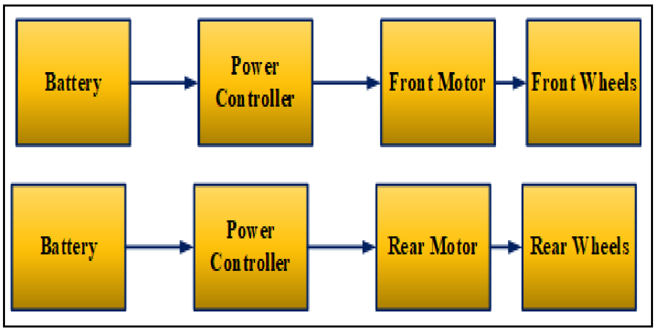

Fig 2 Dual Motor Electric Vehicle Powertrain

Dual motor systems are commonly used in high-performance EVs and all-wheel-drive electric vehicles.

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➢ *Distributed in-Wheel Motor Drive*

In distributed drive systems, individual electric motors are integrated into the wheels. This architecture eliminates traditional transmission systems and improves vehicle dynamics.

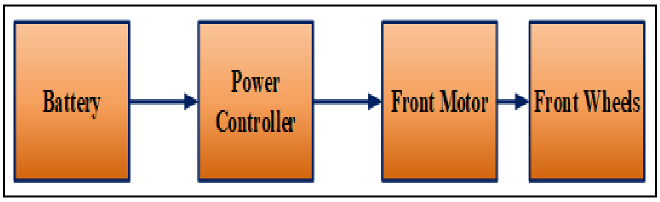

Fig 3 Distributed Drive Electric Vehicle Powertrain

Although this configuration offers excellent efficiency and control, it introduces challenges related to motor protection, unsprang Power Flow Analysis in Hybrid Electric Vehicle.

E. Powertrain Mass, and System Integration.

Hybrid powertrains integrate both electric and mechanical energy sources. The study analyzes the three major HEV configurations.

➢ *Series Hybrid Powertrain*

In a series hybrid system, the internal combustion engine drives an electric generator rather than directly powering the wheels. The generator supplies electrical energy to the motor or charges the battery.

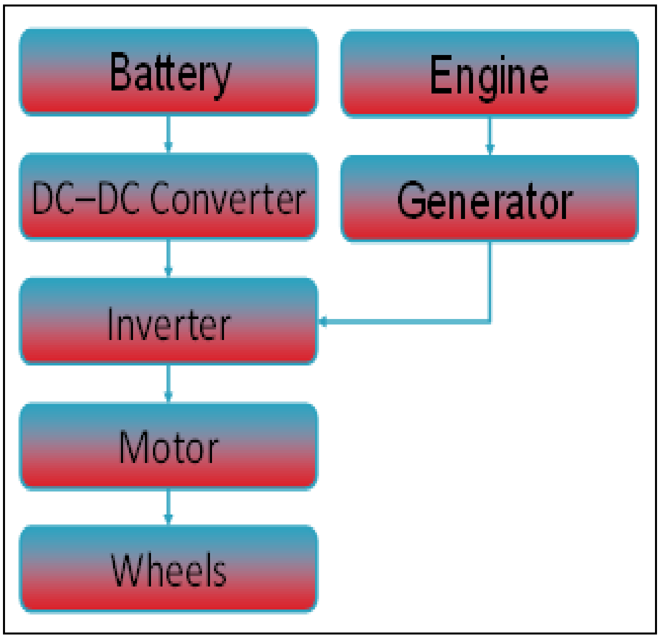

Fig 4 Series Hybrid Powertrain

F. Parallel Hybrid Powertrain

In the parallel hybrid configuration, both the internal combustion engine and the electric motor are mechanically connected to the vehicle drivetrain.

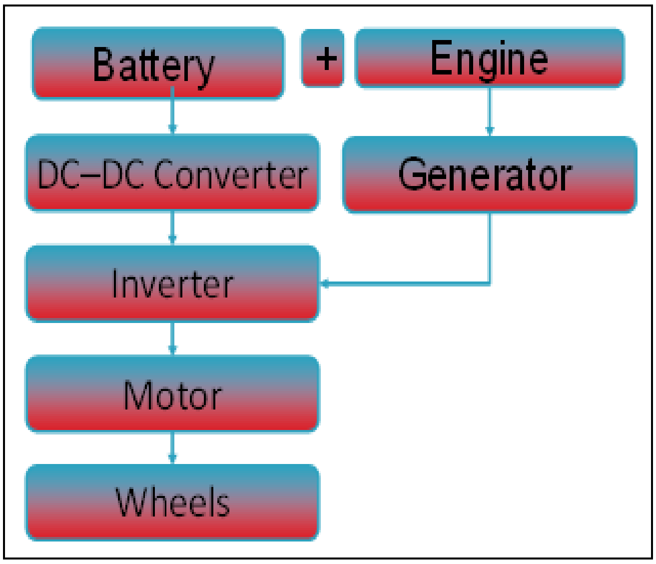

Fig 5 Parallel Hybrid Powertrain

This system improves fuel efficiency by allowing the electric motor to assist the engine during acceleration and low-speed driving.

G. Series–Parallel Hybrid Powertrain

The series–parallel hybrid architecture combines the advantages of both series and parallel configurations. It allows flexible power flow between the engine, generator, battery, and electric motor.

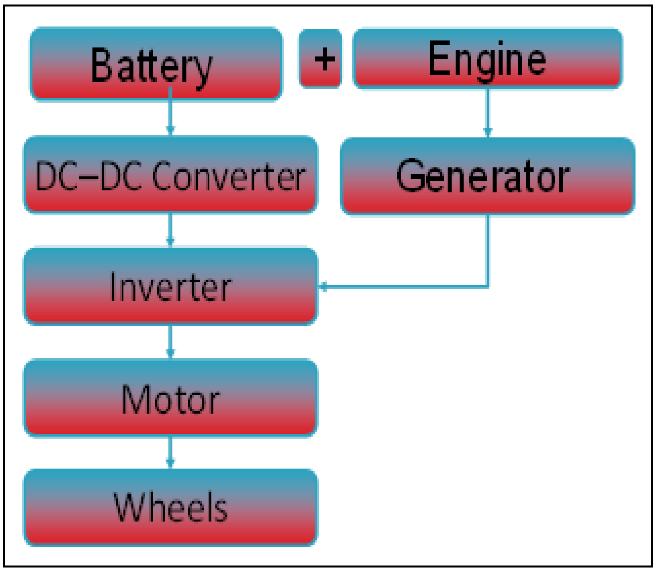

Fig 6 Series–Parallel Hybrid Powertrain

This configuration provides improved fuel efficiency and operational flexibility but increases system complexity and cost.

H. Comparative Analysis

The final stage of the methodology involves comparing EV and HEV powertrain architectures based on the above parameters. A structured comparison table is used to evaluate the advantages and limitations of each topology.

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The comparative analysis helps identify which powertrain architecture is most suitable for specific applications such as urban transportation, long-distance travel, or high-performance vehicles.

III. RESEARCH OUTCOME

The proposed methodology enables a systematic evaluation of modern EV and HEV powertrain systems by integrating structural analysis, energy flow modeling, and performance comparison. The results of this study provide insights into the design considerations and operational trade-offs associated with different powertrain configurations.

The findings also contribute to the development of optimized electric mobility solutions by identifying architectures that offer improved energy efficiency, reduced environmental impact, and enhanced vehicle performance.

IV. CONCLUSION

The comparative study of powertrain topologies in Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) highlights the significant role that powertrain architecture plays in determining vehicle efficiency, performance, and environmental impact. As the transportation sector continues to transition toward sustainable mobility solutions, electrified powertrains have emerged as viable alternatives to conventional internal combustion engine vehicles. This study examined the structural configurations, operational characteristics, and energy flow mechanisms of major EV and HEV powertrain topologies, including single motor electric drives, dual motor systems, distributed in-wheel motor architectures, and hybrid configurations such as series, parallel, and series–parallel systems. The analysis reveals that electric vehicle powertrains provide higher energy efficiency, lower emissions, and simpler mechanical structures due to the absence of combustion engines and complex transmission systems. However, challenges related to battery capacity, charging infrastructure, and initial vehicle cost remain important considerations for widespread EV adoption. Hybrid electric vehicles, on the other hand, offer a practical transitional solution by combining the advantages of both electric propulsion and conventional engines, resulting in improved fuel efficiency and extended driving range. Among hybrid configurations, the series–parallel architecture provides greater flexibility in power distribution and better overall efficiency, although it introduces higher system complexity. The study also emphasizes the importance of advanced power electronics, battery technologies, and intelligent energy management systems in enhancing the performance of modern electrified vehicles. Furthermore, the comparative evaluation demonstrates that the suitability of a particular powertrain topology largely depends on the intended application, driving conditions, and performance requirements. Therefore, continued research in powertrain optimization, battery innovation, and control strategies is essential to overcome existing technological limitations and further improve the efficiency and reliability of EV and HEV systems. Overall, the findings of this peer study contribute to a deeper understanding of electrified vehicle architectures and support the ongoing development of sustainable, energy-efficient transportation technologies for future mobility.

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