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Design, Development, and Review of Electric Vehicle Systems

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Abstract: *The growing demand for sustainable transportation has driven significant advancements in Electric Vehicle (EV) technologies. This paper primarily focuses on the design, development, and evaluation of traction motor systems, which are essential for optimizing the performance and efficiency of EV s. The study explores the integration of advanced energy storage solutions with traction motors, examining their interaction to maximize vehicle efficiency and overall system performance. Additionally, the paper investigates the challenges associated with the development of traction motor systems, including cost, scalability, and thermal management. It further reviews innovations in motor control strategies and regenerative braking technologies that contribute to energy recovery, enhance motor lifespan, and improve overall energy efficiency. The impact of these technologies on vehicle performance and sustainability is analyzed in depth, with an emphasis on their part in lowering carbon emissions and encouraging environmentally friendly modes of transportation. By synthesizing current trends and technological advancements, this research provides valuable insights into the evolving field of traction motors and their vital contribution to the future of electric mobility and sustainable transportation solutions.*
Keywords: *Electric vehicle, traction motor, energy efficiency, transportation system*.

1. Introduction

The rising threat of global warming, significantly caused by carbon emissions from vehicles, necessitates the introduction of EVs on roads, which can play a pivotal role in combating air pollution. Addressing this issue involves developing EVs powered by zero-emission motors that operate on electricity stored in batteries rather than relying on fossil fuels. Another key advantage of EVs is their low maintenance and operational costs. Furthermore, these vehicles offer smooth acceleration with frequent starts and stops, ensuring the system remains free from overload. The automobile industry has recognised New Energy Vehicles (NEVs) as a crucial area of advancement, driven by the emission reduction targets set forth in the Paris Climate Agreement [1,2]. European countries and automakers have already planned to phase out fuel-powered automobiles while the Chinese government has set lofty goals for the following 15 years with the publishing of the NEV Industry Development Plan (2021–2035). China produced and sold 1.242 million NEVs in 2019 and 1.206 million units, respectively, according to statistics provided by the China Association of Automobile Manufacturers (CAAM) [3]. By 2020, these figures increased to 1.366 million and 1.367 million units. EVs, in fact, share a history as long as automobiles themselves. Lightweight experimental EVs first emerged in the mid-1830s and became the most popular vehicle type in the United States at the start of the 20th century. However, following World War I, EVs lost favor to Internal Combustion Engine (ICE) vehicles and eventually vanished from the market. Factors such as limited range and high battery costs significantly contributed to the dominance of ICE vehicles [4, 5]. This does not contribute to the smog that worsens the already severe air pollution in the city. Its quick torque delivery makes it perfect for motorsports. Furthermore, its reduced infrared output and quiet operation make it highly suitable for use in military settings. The energy industry is undergoing a major transformation, with Renewable Energy Sources (RESs) becoming increasingly popular. Simultaneously, the development of the "smart grid," an advanced electrical network, is underway. EVs are considered an integral part of this modern energy system, which incorporates renewable energy and upgraded grid infrastructure. These advancements have sparked renewed focus on and innovation in this method of transportation. The idea of applying Electric Motors (EMs) in vehicles was conceived shortly after motors were invented. By the late 19th century, nearly 28% of vehicles were electric and often preferred over vehicles powered by Internal Combustion Engines (ICEs). However, the availability of inexpensive oil allowed ICE vehicles to rapidly dominate the market, achieving remarkable advancements. Although EVs were largely sidelined, a revival opportunity arose in 1996 when General Motors introduced the EV1 concept. Shortly after, leading manufacturers such as Ford, Toyota, and Honda launched their own electric models. Notably, Toyota's Prius became the first Hybrid Electric Vehicle (HEV) to achieve widespread commercial success. Traction motors for NEVs must be tailored to withstand challenging operational conditions, unlike standard industrial motors. Their functions frequently shift between driving and energy generation. They require capabilities such as frequent stopping and starting, rapid acceleration and deceleration, high torque at low speeds, and strong power for steep inclines at high speeds. Additionally, they must offer high energy density, an extensive efficient operational range, low levels of noise and vibration, exceptional dependability, and a competitive cost-to-performance ratio to satisfy automotive demands. NEVs also rely on integrated powertrain systems that combine gears, clutches, and other mechanical components with motors and controllers. The simplified architecture of the e-powertrain significantly optimizes vehicle design, with its configurations playing a critical role in determining NEV performance. The automotive industry is now a major contributor to both the global economy and in the area of Research and Development (R&D). Technological advancements have transformed vehicles, equipping them with features that emphasize pedestrian and passenger safety [6]. This progress has resulted in a surge in the number of vehicles on the road, offering swift and comfortable travel. Yet, this development comes with drawbacks. Urban regions have experienced a marked increase in pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matter (PM). While the automobile sector has revolutionized daily life with technological and transportation innovations, it has simultaneously caused considerable environmental harm. As progress continues, addressing the environmental challenges posed by this industry must become a priority. The widespread adoption of EVs has also introduced numerous challenges, including high infrastructure costs, expensive vehicle pricing, insufficient charging facilities, and restricted driving ranges. Among these, battery limitations stand out as the most pressing issue. Over the coming years, EVs will play a central role in smart cities, integrating with interconnected transit systems, public transportation, and related infrastructure. Enhancing battery efficiency and simplifying charging processes will require significant attention. The autonomy of EVs remains a primary concern, driving researchers to develop advanced battery technologies that extend range, reduce costs, and minimize weight and charging times. These factors will ultimately shape the future trajectory of EVs.

2. Literature Review

Zhang and Tirumalasetti et al. presented an Intelligent Transportation System (ITS), which is required for smart cities to address their transportation requirements. A smart city's transportation network should include hassle-free, eco-friendly, networked, and shared vehicles in order to improve public transport services. The EV, which also addresses the world's energy issues, is the best choice. The shared and interconnected layer required for a smart city is supplied by intelligent EVs, also known as Autonomous EVs (AEVs) [7, 8]. According to Saleem and Ravish et al., a number of factors, including a poorly planned urban highway network, troublesome functional and structural elements of the transportation system, an absence of management of traffic facilities, and subpar levels, cause the overall range of urban traffic in different countries to fluctuate greatly from the ideal state. Urban traffic congestion, a spike in accidents, and a rise in noise and air pollution are the results of the fast acceleration of urbanisation and the rise in the number of vehicles. These issues have notably negatively impacted the transport capacity and operational efficiency of urban traffic. In response to these challenges, cities have started to actively develop Intelligent Transportation Systems (ITS) [9, 10]. König et al. have pointed out that as a result of their potential to minimise emissions of greenhouse gases and dependency on fossil fuels, EVs are becoming a more and more popular mode of mobility. Rechargeable batteries power an electric motor, which powers an electric vehicle rather than petrol or diesel. By 2030, the number of people using EVs is expected to have increased thrice from 2011. The detrimental effect of high-tech battery efficiency increases on vehicle autonomy is the reason for this [11]. Koo et al. used annual growth rates to analyse the main IPCs of EVs in South Korea. However, prior research has either concentrated on the technical life cycle of EVs in particular nations or areas, or on one particular EV technological area (such as fuel cell or gearbox technology). It should be mentioned that no literature has yet examined the technical lifespan of EVs in South Korean and international markets. Being the first to compare the South Korean and international markets, this study provides a fresh viewpoint not found in the literature. To identify potential avenues for future studies, the author used yearly growth rates to analyse the fundamental IPCs for EVs; however, their study was restricted to South Korea. The EV business is competitive worldwide, nevertheless, and concentrating just on South Korea misses the technological breakthroughs in the EV industry [12]. Ma et al. have employed text mining and examined international patents pertaining to electric cars (EVs); nevertheless, their study, which concludes in 2016, may not encompass the most recent advancements in technology. Re-examining this topic is crucial given the rapid developments in the EV sector and the introduction of new technology. Thus, using the latest information available, this report looks at the worldwide EV industry through 2023. Higher peak demand, frequency and voltage variations, power quality problems, harmonic distortions, significant electrical consumption, and unexpected dynamic behaviours are just a few of the difficulties that might arise from a high level of EV integration into the transmission system. Additionally, EVs rely on electricity from the grid, often supplied by fossil fuel-based power plants [13]. Dulău., have pointed out that carbon emissions from EVs are dependent on the energy sources used for charging. As the number of EV charging stations increases, it may affect load patterns, safety requirements, and characteristics of the distribution network. To address this and ensure grid reliability, international standards and policies for EVs have been introduced [14]. According to Wang et al., EV charging systems cannot successfully interact with the electrical grid without a certain converter design and control strategies. To promote the broad use of EVs and guarantee reliable grid operations, a number of international norms and standards were just recently developed. Global organisations developed these standards, which include EV charging system software that is easy to use, universal frameworks, and peripheral devices. IEEE, IEC, and SAE organisations have made significant progress in establishing fast-charging standards for AC and DC systems [15]. In order to support the grid and enable G2V and V2G operations, EV charging systems use AC/DC converters and sophisticated control algorithms. The converter topology selected affects the charging system's size, price, effectiveness, and reliability. Sanguesa et al., have predicted that EV sales will grow exponentially, propelled by the development of RESs, increased public fast-charging stations, and easier availability to charging equipment. Numerous initiatives are concentrating on transforming RES infrastructure to enhance EV benefits while supporting grid operations [16]. Shariff et al. have suggested that integrating RESs into EV charging systems has become an appealing solution due to its cost-effectiveness, sustainability, and environmental benefits. Auxiliary services that RESs can offer the grid include lowering peak demand, enhancing power quality, and increasing energy efficiency and dependability. Energy Storage Systems (ESSs), solar photovoltaics, wind power, super capacitors, and fuel cells have all been combined in multiple technologies to provide flexible, affordable, and low-emission power options [17]. Rachel and Grace., have highlighted that battery technology is crucial for the EV market, as challenges such as cost, weight, volume, charging time, and lifespan remain significant obstacles to commercialization. Between 2010 and 2021, the cost of EV batteries has decreased from above $1000/kWh to about $132. Battery prices are predicted to continue declining, hitting $100/kWh around 2023 and 2025 and $61–72/kWh by 2030 [18]. EV investments have increased dramatically, with an emphasis on improving driving range, efficiency, and the affordability of charging and discharging. The EV industry is still in its infancy, but inductive and portable charging technologies are becoming more and more popular research topics. For fast EV charging systems to operate effectively and dependably, power converter topologies are essential. The Vehicle-to-Grid (V2G) application, in which EV batteries can store excess energy and return it to the grid via coordinated control schemes, is another exciting field of study [19]. Verma and Singh have proposed a grid-based EV charging system that combines diesel generators, solar PV, and ESS to guarantee reliable recharging in both grid-dependent and islanded modes. Additionally, they demonstrated a decentralised optimisation method for immediate coordination of wind energy integration into the charging system [20].

3. Research Methodology

The methodology begins with a comprehensive literature review to identify advancements in electric vehicle systems, focusing on traction motor technology and key components. The design phase emphasizes creating innovative solutions for integrating traction motors and optimizing power systems based on theoretical models. Prototypes are developed using industry-standard components, ensuring practical implementation and alignment with existing standards. Experimental validation is conducted through controlled performance tests to evaluate efficiency, reliability, and scalability. Data collected during testing is analyzed to identify strengths and potential areas for improvement. Comparative studies are performed to benchmark results against existing technologies. Challenges encountered during the design and development phases are documented to provide actionable insights. Ethical considerations and sustainability factors are integrated into the development process. This structured approach ensures a robust evaluation and development framework for enhancing electric vehicle systems.

Current State of Ev Charging Technology: Momentum in the current industry is being achieved by electrified transportation, driven by factors such as clean environmental concepts, depletion of fossil fuels, affordability, expanding charging infrastructures, and smart propulsion control strategies. A shift to EVs is being prepared by several major automakers, and the sales of fossil fuel-powered vehicles are planned to be restricted in the future by some countries, including those in Europe and China. It is anticipated that the development of Renewable Energy Systems (RESs), public fast charging stations, and the expanding availability of high charging equipment would all contribute to the exponential growth in EV sales. Many initiatives and advances concentrate on altering RES-powered infrastructures in order to support grid operations and further benefit from EVs. Carbon footprints are consequently being seen to decrease, and EVs are contributing to the grid by way of their charging infrastructure. The adoption of EVs is being aided with numerous governmental measures, including purchasing incentives, subsidies for home charging insulation, advantages for drivers and parking, the establishment of international standards, and increased access to public charging infrastructure. All EVs (AEVs) and Hybrid EVs (HEVs) are the two primary categories of EVs. The only source of power for an AEV is a motor that is managed by its power source. The two subcategories of AEVs are Fuel Cell EVs (FCEV) and Battery EVs (BEV). A power control unit (PCU) and Energy Storage System (ESS) are components of a BEV. A Fuel Cell (FC) and Hydrogen Tank (HT) are connected to the PCU of an FCEV, which means it doesn't need an external charging system. This is how an FCEV differs from a BEV. To charge its storage unit, a BEV, on the other hand, requires a source of electricity from the network. One kind of HEV is a Plug-In Hybrid EV (PHEV), which can be powered by the grid. A PHEV is a vehicle that runs fully on a huge battery pack and has a smaller gasoline engine than a Mild Hybrid Electric Vehicle (MHEV), which mixes electric power with conventional Internal Combustion (ICE). All PHEVs and BEVs fall within the EV category. Figure 1 shows how EVs are categorised and what power sources they use for wheel propulsion.

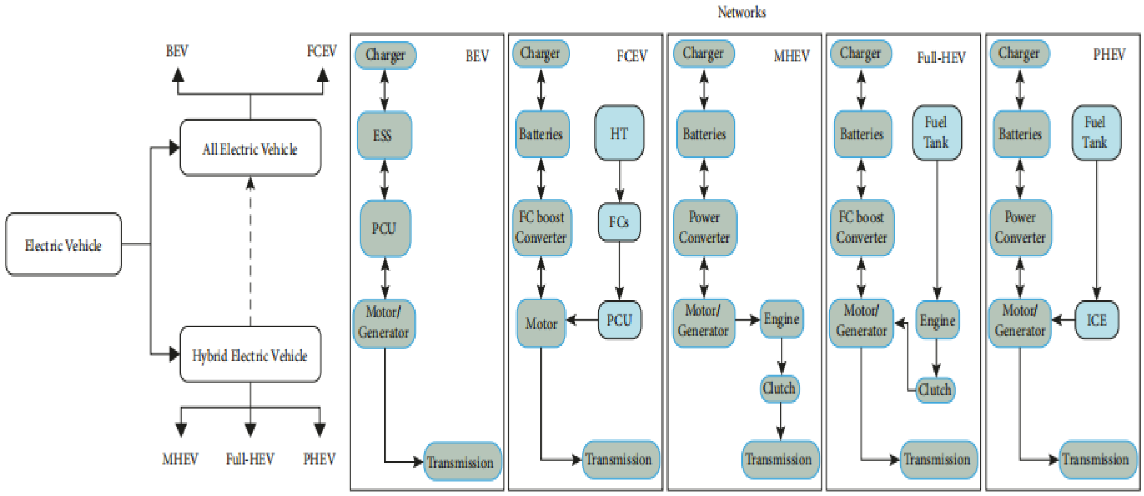

Figure 1. Classifications of EVs.

CHARGING LEVELS AND MODES: For EVs, several charging methods, capacities, and charging and discharging procedures are integrated to satisfy their unique needs. In order to encourage EV adoption in the sector, standardised charging levels and models have been developed, enabling creative breakthroughs and bolstering widely accepted research. A high-power battery pack to control both current and voltage, a battery management device, multiple converters for the right level of voltage, control devices, and drive inverters are all features of contemporary plug-in EVs electric powertrains that bear similarities. EV chargers are classified as onboard or offboard, unidirectional or bidirectional. There are three types of charging technologies: wireless, conductive, and battery switching. In order to replicate the current gasoline station infrastructures Extreme Fast Chargers (XFC) are made to link to a medium-voltage power grid. Moderate and fast charging networks are integrated with a low-voltage transmission grid. In accordance with communication safety limits and power levels, four charging methods and three charging levels are established.

EV-Related Technology: Modern EV Technology: The development of EVs has sparked a lot of attention among professionals, institutions, and significant developers throughout many nations. The field as a whole is separated into numerous main areas that produce increasingly important, precise data, and EVs coordinate a variety of individual accomplishments. EVs help decarbonise transportation because of their advantages, such as having minimal pollution levels, and the creation of reduced-carbon emission cities has become among the models to boost the automotive industry's interest. In any event, development is crucial to the electric vehicle industry's future prosperity. Politicians in nations like Sweden, Malaysia, China, and South Korea are working hard to encourage the scientific advancement of EVs, and these nations are developing measures to support this endeavour. EV technology advancement is regarded as an extremely intriguing topic.

Traction System Control Scheme: Operating a dual stator machine is said to be simple since each stator may be controlled independently, although conventional control methods such as direct torque control, flow control, voltage and field-oriented control are being researched for each AC machine. However, the control system must take into account that a single reference speed is needed, and that six reference signals have to be computed. The reference speed can be used to create the three reference signals that are applied to the particular stator in traditional control systems. It doesn't apply here. It is necessary to build the control architecture appropriately. It is now necessary to explain the connection between the mechanical angle and the revolving stator angles, as shown in equation (1). The link between the rotors' and stators' electrical angles is explained by equation (2). Figure 2 & 3 illustrates the EV powertrain architecture and Specifications of EVs respectively.

$$\omega_{elem} = \frac{\omega_{s,1} + \omega_{s,2}}{(p)} \pi r^2 \tag{1}$$

$$\theta_m = \theta_{s,1} + \theta_{s,1} \tag{2}$$

Either an AC or DC current can excite the system on the main or secondary stator. If a DC current activates one of these stators, the resulting electrical angular direction becomes null.

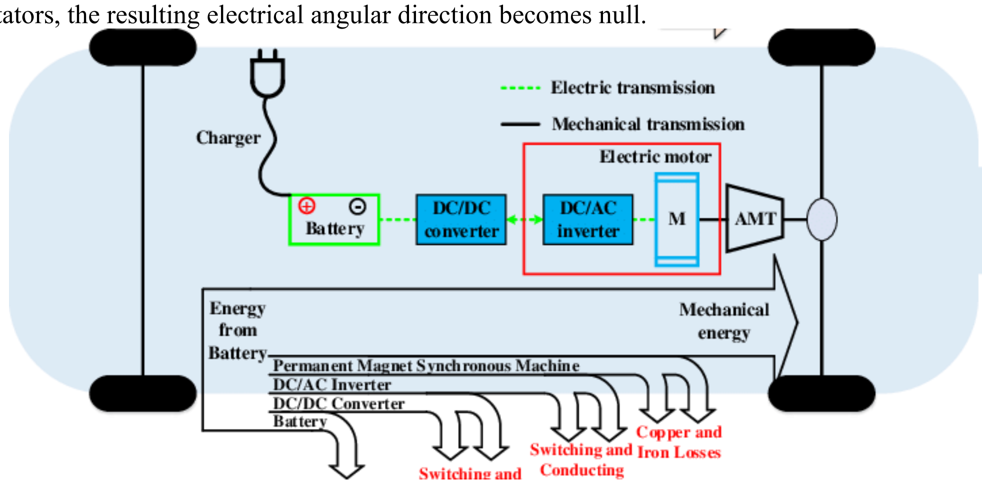

Figure 2. EV Powertrain Architecture

Double Stator Machine Parameters	Maximum Speed	5000 rpm
	Maximum Electric Power	30000 W
	Maximum Current	25/50 A
	Voltage	500 V
Battery Pack Characteristics	Voltage	220V
	The Initial State of Charge	67%
Vehicle and Road Specification	Vehicle Weight	700 kg
	Road Slope	0%
	Maximum Speed	80 km/h

Figure 3. Specifications of EVs

4. Conclusion

This study concludes by highlighting the vital role traction motor systems play in improving the effectiveness and long-term viability of EVs. By integrating advanced energy storage solutions and innovative motor control strategies, the research highlights pathways to enhance energy efficiency, system scalability, and thermal management. The exploration of regenerative braking technologies further emphasizes their potential for energy recovery and extended motor lifespan. These advancements collectively contribute to reducing carbon emissions and fostering eco-friendly transportation. The findings provided an in-depth overview of the issues and trends of the present, for more innovation in developing of sustainable and effective traction motor systems for the development of electric mobility in the future.

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