Review of Traction Motors for Electric Vehicle Application

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Abstract. The accelerating demand for electric vehicles (EVs) and the necessity to reduce fossil fuel dependence have intensified research on advanced traction motor technologies. This paper presents a comparative analysis of key traction motors including DC Series, Induction, Permanent Magnet Synchronous (PMSM), Switch Reluctance (SRM), and Brushless DC (BLDC) motors. A quantitative evaluation is conducted considering torque density, efficiency, and cost-effectiveness. Results indicate that PMSMs achieve peak efficiencies of 93–95% with excellent speed control, while induction motors maintain strong cost-performance ratios. SRMs offer durability and fault tolerance but exhibit torque ripple, whereas BLDCs provide compact integration with high dynamic response. These insights serve as guidelines for EV motor selection. Keywords—Traction Motors, Electric Vehicles, Performance Comparison, Efficiency Analysis, Rare-Earth-Free Motors, Cost Optimization.

Keywords: Traction Motors, Electric Vehicles, Hybrid Electric Vehicles, Brushless DC Motors and Axial Induction Motors

1 Introduction

In the past few decades, global warming, decline in air quality, and depletion of petroleum resources have captured the attention of scientists and quickened their regards to producing an alternative for sustainable development. In evolving countries, particularly in major cities, the transportation industry is one of the major sources of rising harmful exhaust emissions which causes many health diseases. Electrifying propulsion system is widely recognized as a way to enhance fuel economy and decrease greenhouse gas emissions in the transportation industry. In electric vehicle technology, the automobile's movement is energized entirely by electric energy. The electric motor provides the necessary power to drive the vehicle, making it a crucial component of electric vehicles. In electric vehicle technology electric force is the sole source of power for the movement. The electric force is translated into mechanical force

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in electric vehicles. The electric motor provides the necessary power to drive the vehicle, making it a crucial component of electric vehicles [1][2].
Choosing the perfect traction motor for an Electric Vehicle body is a major challenge in the market nowadays. There are numerous vehicles in the market, each using different motors to serve specific purposes. Electric vehicles (EVs) can be equipped with alternating current (AC) motors or direct current (DC) motors, based on their design and purpose. Electric motors have been studied thoroughly and researched which resulted in the development of various types [3][4]. This improvement gave electric automobile manufacturers a choice of different electric motors depending on their requirements. The selection of a particular electric vehicle traction motor must be handled with caution because it directly impacts the general performance of the vehicle [5][6][7].
This paper presents a multi-criteria comparative analysis of electric motors used in electric vehicles (EV). This section discusses the literature on electric vehicle motors, followed by a comparative analysis of various electric motors concerning several criteria that affect crucial parameters like energy efficiency, electrical properties, durability, pros and cons, and maintenance parameters. Conclusions are drawn to determine the most appropriate electric motor for the electric traction system [8][9].

2. TRACTION MOTORS

Traction motors are electric motors that are designed to drive the vehicle's wheels, providing the necessary force for its movement. These are mostly used in both electric vehicles (EVs), hybrid electric vehicles (HEVs), locomotives, and industrial machinery. In Electric Vehicles, the energy produced is electrical energy. These motors transform electrical energy into mechanical power to propel the vehicle efficiently [3][10][11].
Traction motors can either run on alternating current (AC) or direct current (DC) and are chosen based on key factors such as efficiency, torque, and durability.

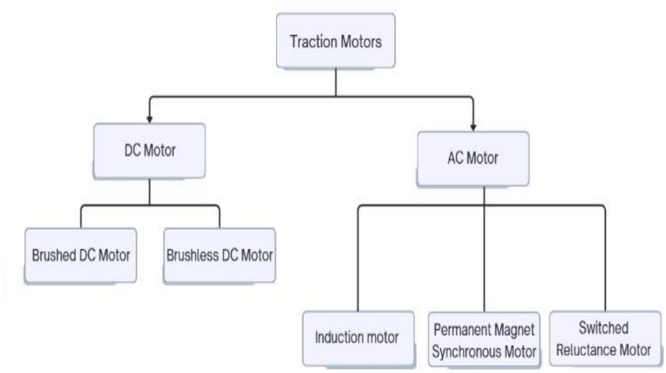

Figure 1. Classification of traction motors utilized in electric vehicles [6]

2.1 Brushed DC Motor

DC refers to Direct Current motors which were designed to achieve efficient performance and very simple to control speed and torque, very nice to accelerate smoothly. This made them very suitable for solving one of EV's problems since even the slightest irritation cannot be accepted. DC motors are mostly chosen due to their simplicity, precision, and reliability. The straightforward operation features an electrical current supplied through a coil of wire inside a magnetic field and creates motion, hence ideal for EV applications.

DC motor is best known for the ability to run with continuous and smooth and precise control of torque and speed, which allows them to instantly respond to an accelerating or decelerating event [12][13[[14]. They are very effective within city limits and for stop-and-go traffic. The DC motor is a type of motor that instantly produce power and torque to get a smooth start from rest and uniformly accelerate at all speeds. DC motors, by the way, are also well-known for the amount of energy conservation they are capable of, especially at lower rates, which are vital for electric vehicles made for everyday use. Their easy manufacture has lead them to have fewer wearing parts, hence, the maintenance costs can be reduced, and the vehicle's overall lifespan can be extended.

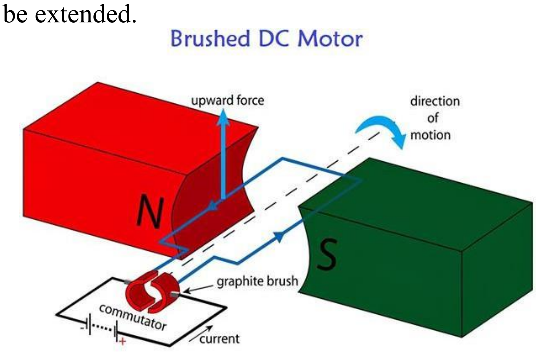

Figure 2. Operational diagram of Brushed DC Motor [6]

This reliability as well a lower installation costs factor makes the DC motors the most popular choice for the majority of electric vehicles, thus other people who are observing or economic usage and long life would prefer them. At the same time, DC motors are still an essential part of the future of electric vehicles. Since the motor is balanced in terms of efficiency, control, and stamina, the electric vehicles will work properly which in turn will make them an indispensable part in the transition to environment-friendly accommodation.

Limitations of DC motors: DC motors, however simple and manageable, possess many drawbacks. They need frequent maintenance due to brush deterioration, resulting in lower lifespan and possible reliability problems. They are less effective at higher speeds and can be plagued by sparking and electromagnetic interference. The requirement of a mechanical commutator is to generate greater friction and wear. Furthermore, DC motors are less efficient in energy conversion, particularly in high-power applications, and need a stable DC power supply for optimal performance [15][16].

2.2 BLDC Motor

With the advent of electric vehicles (EVs), some of the majorly enhanced components changing the tide of the entire industry are the *BLDC motor, or Brushless DC motor. Picture you on a stylish, noiseless EV on a bustling city street! The vehicle is never jerky but a delicate ride with minimal friction and maximum effectiveness. Very much the BLDC motor does is to incorporate such advantages, playing a significant role in boosting up the demand for electric vehicles [7][17][18]. A. The design of the motor marks the beginning of the evolution of the BLDC motor. It fundamentally makes use of permanent magnets on the rotor, and unlike traditional brushed motors, which have electrical connectors that use brushes, the BLDC motor relies purely on the electronic controller for driving duty. The absence of brushes means that BLDC motors are not only more durable, but much quieter-a very vital quality for any EV. BLDC motors offer a wide flexibility relating to torque and power in their construction, accommodating diverse requirements of various types of EVs, starting from small city cars to huge trucks. Their compactness allows them to be compatible with the lightweight and limited space constraints a developing EV architecture demands.

The reliability and low maintenance of BLDC motors is also of great significance for the long-term success of EVs. A significantly longer lifetime is attested to by the much lesser number of moving parts, as well as their absence of brushes which wear out, thereby bringing down repair and maintenance costs. In short, these motors are the true backbone of the EV revolution.
They combine efficiency, durability, and versatility, rendering electric vehicles quiet, reliable, and energy efficient on and off the highway. The role of the BLDC motor in shaping the future of transportation cannot be overemphasized as the EV technologies have grown.
BLDC motors, while efficient and durable, have several limitations. They require complex electronic controllers for commutation, which increases cost and design complexity. Many BLDC motors depend on sensors for proper operation, adding to their expense. At low speeds, their efficiency and torque decrease. They also tend to overheat under heavy loads if cooling is inadequate. Additionally, they need a stable DC power supply and can become bulky due to the added components [20][21].Colour illustrations
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2.3 Permanent Magnet Synchronous Motor (PMSM)

Permanent Magnet Synchronous Motor (PMSM) gained popularity as a revolutionary product in the mid-20th century when industries needed efficient and reliable motor-driven solutions. Traditional motors were besieged by problems like energy wastage, mechanical wear and tear, and costly maintenance. The PMSM was created to address these problems by employing permanent magnets rather than electromagnets to create the motor's magnetic field, making it more efficient and power saving. Brush and commutator removal, typical in DC motors, also provided increased longevity, maintenance-free operation, and longer lifespan, which made the PMSMs suitable for highly controlled, high- efficiency demanding, small and space-saving applications like robots and electric vehicles [4][8][22].
PMSMs became increasingly popular because they were energy efficient in the sense that they generated more power but at reduced power consumption. They also provided higher torque density in limited space, and hence, they were a must where power output and space are factors. Their synchronous precise drive ensured precise speed and position control, which was essential in cases where precision is high. There was also no presence of brushes, which equated to less noise and smooth operation, and this was a significant factor where noise was important. When companies had started emphasizing sustainability, the energy efficiency of PMSMs and their lower maintenance requirements made them a more environmentally friendly option over conventional motors, with a lower environmental impact. Essentially, PMSMs were created to address the increasing need for sophisticated, affordable, and eco-friendly motor solutions, where performance and efficiency are well balanced in most contemporary
Limitations of Permanent Magnet Synchronous motor: They require precise control systems for operation, making them more complex and costly to implement. The use of permanent magnets can lead to high initial costs, and rare- earth materials used in these magnets can be expensive and subject to supply fluctuations. PMSMs also have limited torque at low speeds, making them less efficient in such conditions. Additionally, they can suffer from overheating in high-load situations and may require complex cooling.

2.4 Induction Motor

Induction motors serve an important purpose in hybrid electric vehicles (HEVs) since they provide efficiency and reliability and do not use excitation. An induction motor is an asynchronous AC motor that works on the principle of electromagnetic induction, in which the rotating magnetic field created by the stator binding induces current when in the rotor for motion. Induction motors are generally found in asynchronous motors; they do not have an independent external excitation for their rotors. Rather, they work with the principle of developing torque due to the interaction between a rotor and an induced current caused by the stator's rotating magnetic field, producing high efficiency and being self- started [21],[23].

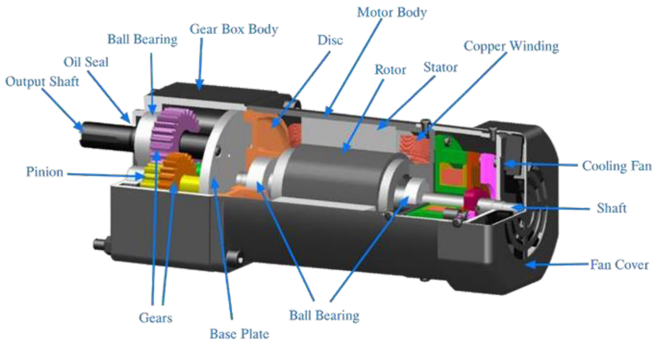

Figure 3. Operational diagram of Induction motor

Electric motors, generally induction motors, in HEVs are concerned with their functioning whereby electrical energy is translated to mechanical energy that propels the vehicle. Induction motors in HEVs were mostly more efficient with lower emissions and regenerative braking as compared to conventional internal combustion engine (ICE) vehicles developed for the contemporary automotive industry using hybrid and electric power trains. The SCIM is uniquely favoured in HEVs because it has a rugged design, a high ratio of torque to weight, and is able to perform under a wide range of speeds and applications. At times wound rotor induction motors are utilized in applications where high torque performance is essential and indeed, speed variations have to be adopted. Induction motors have been used in electric and hybrid vehicles by major automakers such as Tesla, Toyota, and General Motors because of their cost-effective production and high standards of performance. With demand for eco-friendly transportation significantly on the rise, induction motors remain a potent force in developing HEV technology that improves energy efficiency and provides cleaning features.

2.5 Switched Reluctance Motor

Switched Reluctance Motors (SRMs) are becoming increasingly popular in both Hybrid Electric Vehicles(HEVs) and Electric Vehicles(EVs) because of their numerous advantages. Their straightforward design, which lacks complex windings or magnets in the rotor, leads to lower manufacturing costs and greater durability, both essential for the reliability of EVs and HEVs. SRMs also provide high efficiency, which optimizes the conversion of electrical energy into mechanical power, a crucial element for extending the range of EVs and enhancing the fuel economy of HEVs. This efficiency, along with strong torque and speed capabilities and a broad range of constant power bands, makes them ideal for various driving conditions. Although integrating SRMs into HEVs has posed challenges due to the requirement for advanced power electronic converters and historically lower torque density, improvements in power electronics are addressing these concerns. Modern power electronic converters allow for precise control, enhancing the performance and efficiency of SRMs in both EV and HEV applications, and boosting torque output to levels comparable to other high-performance traction motors.

Figure 4. Operational diagram of Switched reluctance motor

Current research is aimed at refining control systems to minimize torque ripple for smoother operation, increasing power density for more compact designs, and investigating innovative concepts like integrated flux control to further improve HEV performance. Additionally, efforts are underway to combine SRMs with other technologies in EVs and HEVs, such as regenerative braking and battery management systems. In summary, SRMs present a strong alternative for electric propulsion, and with ongoing advancements, they are set to significantly influence the future of both electric and hybrid transportation systems.

2.6 Axial Flux Motor

Axial Flux Motors (AFMs) are gaining popularity in Hybrid Electric Vehicles (HEVs) because they give high torque density, a compact design, and impressive efficiency, ideal for HEV applications. These motors have a shorter axial length and a larger diameter than traditional radial flux machines. Although there are challenges related to manufacturing and rotor dynamics, ongoing research is paving the way for effective solutions. Additionally, advanced control algorithms are vital in enhancing AFM performance in HEVs

Table Comparison of various traction motors for EV applications

Name	Features	Advantages	Limitations	Usage
Brushed DC Motor	Simple Construction: Comprises basic components, making it easy to manufacture and repair. Variable Speed Control: Speed can be easily adjusted by varying the supply voltage. Cost-Effective: Lower initial cost compared to brushless motors.	Simple and cost-effective design: Requires fewer electronic components compared to brushless motors. High starting torque: Ideal for applications requiring strong initial force. Easy speed control: Speed can be adjusted by varying the supply voltage.	Brush wear and tear: Brushes degrade over time, requiring regular maintenance. Lower efficiency: Friction between brushes and the commutator results in energy losses. Shorter lifespan: Compared to brushless motors, brushed motors have a shorter operational life.	Home Appliances: Found in vacuum cleaners, fans, and food processors. Toys and Hobbyist Devices: Commonly used in small- scale electric devices.
BLDC Motor	Uses electronic commutation instead of brushes. High efficiency and power density. Requires a controller for operation. Lightweight and compact design.	High Efficiency: Reduced energy loss because the absence of brushes. Longer Lifespan: No brush wear, leading to minimal maintenance. Better Speed Control: Precise	Complex Control System: Requires an electronic controller, increasing cost. Higher Initial Cost: More expensive than brushed DC motors. Electromagnetic Interference (EMI): Due to high-frequency switching.	Drones & Robotics: High precision and lightweight applications. Medical Equipment: Pumps and ventilators for silent operation. Industrial Automation: CNC

		control over speed and torque.		machines and conveyor systems.
PMSM	Uses permanent magnets in the rotor for field generation. Low energy losses due to absence of field windings. Smaller and lighter than traditional motors with wound rotors.	Low energy loss due to the use of permanent magnets Smaller size and lighter than other motors with similar power output. Fewer moving parts, leading to lower wear and maintenance needs	Limited Overload Capacity – Induction motors have a limited ability to handle overloads compared to induction and DC motors	Powers motors in electric cars and scooters. Drives fans and pumps in heating and cooling systems. Used in precise positioning and movement in robotic applications
Induction Motor	Operates on electromagnetic induction (no physical connection to rotor for power transfer). Self-starting and requires no external excitation. Rugged and durable construction with minimal maintenance Available in Squirrel Cage (SCIM) and Wound Rotor (WRIM) types High efficiency and reliable operation over a wide speed range	High efficiency at variable loads, improving vehicle performance. No need for rare-earth magnets, reducing production costs compared to Permanent Magnet Motors (PMSMs). Low maintenance due to absence of brushes and commutators. Capable of high torque generation, suitable for various vehicle driving conditions	Limited Overload Capacity – Induction motors have a limited ability to handle overloads compared to synchronous and DC motors Not Suitable for High Precision Applications – Due to speed variations and lack of precise control, induction motors are not ideal for applications requiring high accuracy.	Used in regenerative braking in which the kinetic energy is converted into electrical energy. Traction motor for propulsion in hybrid and electric vehicles Integrated into powertrain systems for smooth acceleration and torque control Applied in parallel and series hybrid systems for better fuel efficiency Utilized in electric vehicle cooling pumps, compressors, and auxiliary systems
Switched reluctance motor	Simple Design: Minimal components, no permanent magnets. High Torque: Strong performance at low speeds. Durable: Robust against harsh conditions	High Efficiency: Good performance across various speeds Cost-Effective: Lower manufacturing costs. Low Maintenance: Fewer wear parts; no brushes. Thermal Performance: Efficient cooling capabilities. Flexible Control: Precise torque and speed regulation	High Torque Ripple – SRMs exhibit significant torque ripple due to variable nature of their magnetic field, leading to vibration and noise issues. Acoustic Noise & Vibration – The pulsed excitation of stator windings and rotor structure can cause excessive noise and vibrations.	Electric Vehicles: Traction systems Industry: Drives for pumps, fans, and conveyors. Home Appliances: These are found in washing machines and vacuum cleaners. Robotics: Used in actuators Renewable Energy: Applications in wind and solar systems.

Axial flux motor	Compact & Lightweight: Shorter axial length compared to radial flux motors. High Power Density: More power output in a smaller size. Better Cooling Efficiency: Improved heat dissipation due to its structure. Higher Torque Output: Generates more torque with the same size as radial flux motors. Dual Rotor or Stator Design: Offers flexible configurations for performance optimization.	Efficient Use of Space: Ideal for compact applications like EVs and drones. Higher Efficiency: Reduced iron and copper losses improve energy efficiency. Reduced Material Usage: Uses less copper and iron, making it cost-effective. Better Performance at Low Speeds: Delivers high torque without requiring high RPM.	Manufacturing Complexity: More difficult and expensive to produce. High Initial Cost: Due to advanced materials and precision manufacturing. Control Complexity: Requires precise control and specialized electronics. Thermal Management Issues: Can overheat if not designed with proper cooling	Electric Vehicles (EVs): These are used in high-performance EVs for better power-to-weight ratio. Aerospace & Drones: Preferred due to their lightweight and high efficiency. Wind Turbines: Utilized for compact and efficient energy conversion. Industrial & Robotics Applications: Provides high torque in limited space

This research focuses on [specifically state your AFM research focus, e.g., optimizing AFM drive efficiency for improved HEV fuel economy, or designing an AFM for enhanced regenerative braking], which could fill a significant gap in the use of AFMs. The study aims to explore innovative AFM designs that utilize advanced materials or unique winding techniques. In particular, this work investigates [mention the specific technique or material, e.g., model predictive control, or a specific composite material], which shows great potential for HEV propulsion. The objective is to develop ultra-compact and efficient HEV systems. The proposed methodology outlines the specific AFM design or control algorithm, including [mention the specific technique or material]. The performance will be thoroughly assessed through simulations and, when possible, experimental tests, showcasing effectiveness in realistic HEV scenarios and measuring enhancements in fuel economy and regenerative braking.

3. CONCLUSIONS

The evolution of traction motor technologies has played a critical role in advancing electric vehicle (EV) performance, efficiency, and sustainability. This paper has examined various types of traction motors, including Brushed DC Motor, BLDC Motor, Permanent Magnet Synchronous Motor(PMSM), Induction Motor, Switched Reluctance Motor(SRM) and Axial Flux Motor along with their applications, advantages, and limitations.

The choice of an optimal traction motor depends on various factors, including vehicle type, cost constraints, efficiency requirements, and sustainability considerations. As the EV industry continues to expand, future research will likely focus on improving motor efficiency, reducing material dependencies, and developing advanced manufacturing techniques to enhance performance and reduce environmental impact. Overall, advancements in traction motor technologies will continue to drive the growth of the EV market, supporting global efforts toward cleaner and more sustainable transportation

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