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Comparison of Different Motor Topologies for Electric Vehicle Drives

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Abstract

This review paper presents a comprehensive comparison of different motor topologies used in electric vehicles (EVs), including induction motors (IMs), DC motors, and permanent magnet synchronous motors (PMSMs). The primary part of an EV is its motor. It is crucial to choose a motor type and rating that are appropriate. The advantages and disadvantages of each topology are evaluated, along with their performance metrics, such as efficiency, power density, torque ripple, maintenance, reliability and speed range. The paper provides a valuable resource for researchers, engineers, and manufacturers in the EV industry, guiding the selection of the most suitable motor topology for EV applications.

Keywords
Electric vehicles, motor topologies, efficiency, power density, torque ripple

1. Introduction
Conventional vehicle design has the effect of greenhouse and has brought many ideas to the researchers worldwide to seek an alternative way of reducing greenhouse gasses one of those gases is CO2 emission that cause by combustion of fuel and principal petroleum, transformation from internal combustion engine (ICE) to the use of electrical machines for electrical drives vehicles. Electric drive vehicles are using electricity as primary fuel and it's also play a significant role for the reduction of environmental pollution, it's reduce the level of greenhouse gases which is Carbon dioxide (CO2). The world is facing the challenges of climate condition and this gives everyone who has impact on polluting the air especial industries to seek alternative way to improve the system and reduce CO2, Car industry has improved better by introducing electric drive vehicles system and this make the different especial to the habitant. The design of electric vehicles has a good impact for improving efficiency of conventional vehicle design. Electric vehicles are divided into three categories which include Hybrid electric vehicles (HEVs), Plug-in hybrid electric (PHEVs) and all-electric vehicles (EVs). Hybrid electric vehicles are powered by an internal combustion engine (ICE) and by electrical motor that utilise energy that stored in the battery (Azab 2025, Mehrjardi and Ehsani 2013). The extra power provided by the electric motor enable for smaller engine without sacrificing performance. The PHEVs induce no tailpipe emissions even when the internal combustions engine is operating. PHEVs consume less gasoline and typically produce lower emissions than similar conventional vehicles and the performance is similarly to HEVs. An electric vehicle (EV) is a vehicle that uses one or more electric motors for propulsion, powered by a battery or other energy storage device. EVs can be powered solely by electricity, or they can be hybrid vehicles that combine an electric motor

with an internal combustion engine. This paper presents comparison of different motor topologies used in electric vehicles. (Wakefield 1998, Jagadeeshwaran and Kumar 2013) (10 font)

1.1. Literature Review

The Objective of the review paper to review and compare the different motor topologies for EV drives. The increasing demand for electric vehicles (EVs) has driven the need for efficient, reliable, and cost-effective electric drive systems. The motor is a critical component of the electric drive system, responsible for converting electrical energy from the battery to mechanical energy to propel the vehicle. With various motor topologies available, selecting the most suitable one for EV applications is a complex task. This paper provides a comprehensive comparison of different motor topologies used in EVs, including induction motors (IMs), DC motors, permanent magnet synchronous motors (PMSMs), and The paper evaluates the advantages and disadvantages of each topology, their performance metrics, and application suitability (Figure 1- Figure 15) providing a valuable resource for researchers, engineers, and manufacturers in the EV industry. (Azab 2025, Mehrjardi and Ehsani 2013,; Wakefield 1998,; Jagadeeshwaran and Kumar 2013).

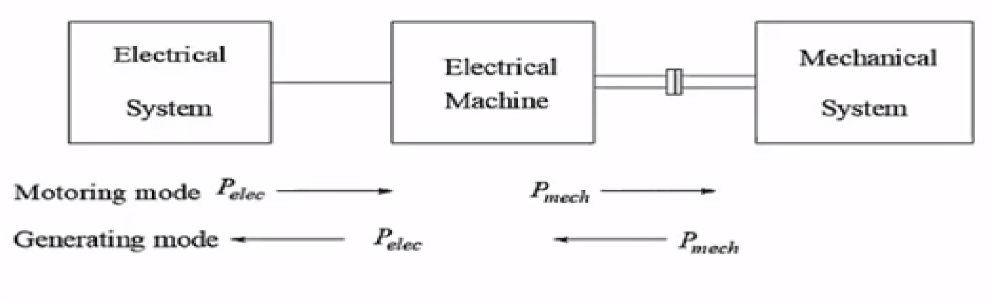

Figure 1. Electric Drive.

Electric drives for electric vehicles are made up of mechanical, electrical, and electrical systems (Mehrjardi and Ehsani et al.2013). Electric drive can be built with source, power modulation, motor, load sensing unit and control unit and input command. Power modulator: During transient operations like starting, braking, and speed reversing, the power modulator regulates the output source and controls the power from the source to the motor in such a way that the motor transmits the speed torque characteristic required by the load, reversing the excessive current drawn from the source. At low voltage and power levels, the power modulator is managed by the control unit. The sensing unit detects specific drive parameters, such as motor speed and current. (Sing et al .2020.; Thangavel et al .2020)

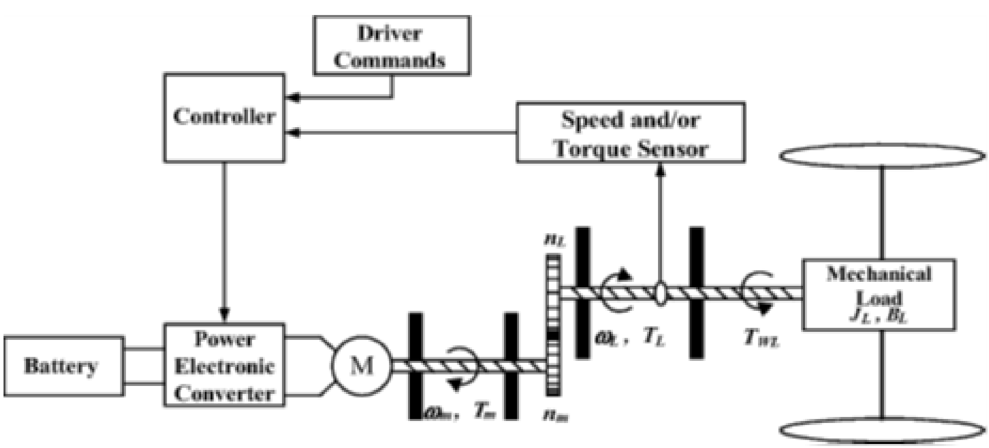

Figure 2. Main components in electric drive circuit (Yokochi et al.2020).

The battery, power electronic converter, DC motor/AC motor, and controller are the primary parts of the electrical drive circuit in Figure 2, Each of these parts is crucial to electric vehicles.

2. Motor Topologies

2.1 Induction Motors (IMs)

Induction motors as a brushless drive are widely used for electric vehicles due to their low cost, high reliability and easy when comes to maintenance. Induction motor is limited such as voltage variable frequency. Induction motor at present of induction motor drives are the most mature technology among commutator less motor drives. In the late 19th century, Serbian-American inventor and physicist Nikola Tesla created the induction motor. In 1887, Tesla created the first usable AC induction motor, and many contemporary electric motors still use his design. The widespread use of AC power in homes, businesses, and transportation was made possible by Tesla's work on the induction motor, which was a significant advancement in the development of electric power systems. (Marulasiddappa and Pushparajesh 2021).

Induction motors come in two varieties: wound-rotor cage motors. Wound rotor induction motors are less appealing than their squirrel-cage counterparts due to their high cost, maintenance requirements, and lack of durability, particularly for electric propulsion in EVs and HEVs.The Benefits of Induction Motors High efficiency, self-starting, low maintenance, and economical. The drawbacks of induction motors Heat production, restricted control, low starting torque, and speed regulation. (Jagadeeshwaran and Kumar 2013.; Thangavel et al 2020; Marulasiddappa and Pushparajesh 2021)

Design of Different Slots
There are several varieties of slots, such as tapered, semiclosed, and open slots.
Open and semiclosed stator slots are the two types commonly used in induction motors. The shape of the slots determines how well induction motors operate, thus choosing the right slot for the stator slots is crucial.

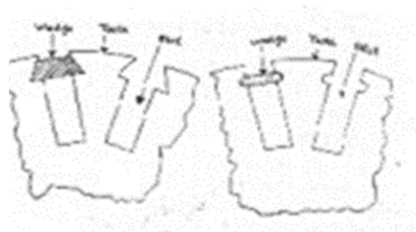

Figure 3. Design of open slots

Winding assembly and repair are simple in these kinds of slots. But these slots will result in a larger air gap. Three-phase induction motors hardly ever use these kinds of slots and the slot opening in these kinds of slots will match the slots' width.

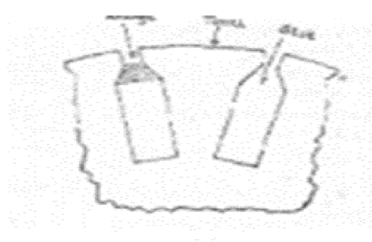

Figure 4. Design of Semiclosed slots.

As a result, winding assembly in these slots is more challenging and time-consuming than in open slots, which makes them more expensive. On the other hand, compared to open type slots, the air gap properties are superior and the slot opening in these kinds of slots is substantially smaller than the slot's width.

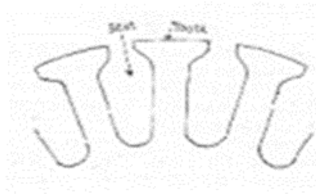

Figure 5. Design of Tapered slots

The slot's minimum width will vary from the top to the bottom of the slot. The opening will be significantly less than the slot width with this kind of slot as well.

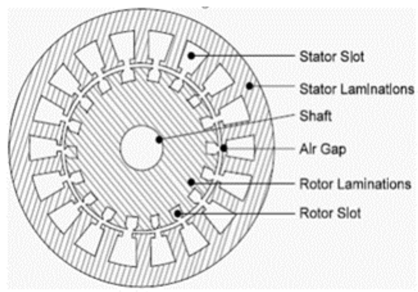

Figure 6. Stator design for induction motor.

When three-phase AC is fed to the stator, a spinning magnetic field is produced. An induction motor's stator design is made up of stator slots and stator core. The choice of stator slot count, the number of stator slots has an impact on the motor's weight, cost, and operating characteristics, hence it must be carefully chosen during the design phase. The benefits of choosing more slots are listed below. decreased leakage reactance, decreased tooth pulsation losses, and increased overload capacity. The drawbacks include inadequate cooling, rising temperatures, higher iron losses, and higher expenses. (Gritter et al.2002)

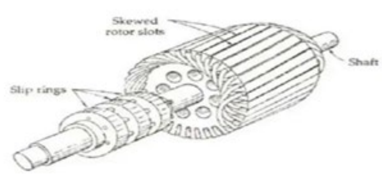

Figure 7. Squirrel –cage rotor design of induction motor

The revolving component of an induction motor is called the rotor. It is installed on the motor shaft that powers an EV's wheels and resides inside the stator. It transforms the stator's electrical energy

3. DC Motor

A DC motor works on the basis of the idea that a current-carrying conductor experiences a mechanical force when it is put in a magnetic field. Fleming's Left Hand Rule dictates the force's direction, and the following relation provides its magnitude: Bil Newton is F. (Yokochi et al.2020). Dc motor this is a type of electrical machines that convert electrical input energy into mechanical output, the conversion takes place in the form of rotation through direct current and convert this energy into mechanical output, there are various types of DC motors, such as DC Series, DC Brushed, DC Shunt, and DC Brushless motors. These types of DC motors also offer precise advantages and disadvantages when compared to each other in terms of their functionality; the choice of DC motor depends on its performance, advantage, and disadvantage is carefully considered. DC Brushless is a potential machine among the other types of DC machines that that is suitable in electric vehicles; it is safer and more durable than the other classical design. (Basu et al.2021)

3.1 Basic Equations for DC Motor

According to Equation 1, where kT is the torque constant, the torque Tem is proportional to the armature current Ia.

$$T_{em} = k_t \times I_a \quad (1)$$

The rate of change of magnetic flux dϕ/dt increases in proportion to the rotor speed as the motor rotates more quickly. Equation 2 provides this, where ke is the back-emf constant and ωm is the motor speed.

$$e_a = k_E w_m \quad (2)$$

The voltage applied at the terminal Va is equal to the back-emf Ea plus the total voltage across the passive elements Ra and La.

$$v_a = e_a + R_a i_a + L_a \frac{di_a}{dt} \quad (3)$$

$$\frac{dw_m}{dt} = \frac{1}{j_{eq}}(T_{em} - T_L) \quad (4)$$

For steady state

The armature current is inversely related to the torque constant and proportionate to the electromagnetic torque.

$I_a =$ armature current

$T_{em} =$ electromagnetic torque

$T_L =$ load torque

$K_E =$ constant torque

$$I_a = \frac{T_{em}(= T_L)}{k_t} \quad (5)$$

The motor speed ωm is proportional to the voltage applied

To the terminal voltage –IaRa and proportional to the constant torque

$$w_m = \frac{v_a - I_a R_a}{k_E} \quad (6)$$

Figure 8. Dc Motor Stator Design

A stator is a stationary component that produces a steady magnetic field. Permanent magnet stators and wound field stators are the two types of stators. PMs are used on the stator housing of permanent magnet stators. common in e-bikes, forklifts, and compact EVs. Field current is not required. Copper windings on stator poles, wound field stator. A static N-S magnetic field is created across the rotor by the battery's current, which also permits field weakening for increased speed. It acts as the framework for creating the rotating magnetic field and is usually constructed of laminated steel to minimize energy losses from eddy currents. Field windings or permanent magnets in the stator produce a steady magnetic flux that controls the electric motor's operating efficiency. The stator's terminals receive electrical electricity, which starts the electromagnetic interaction needed for motor spinning.

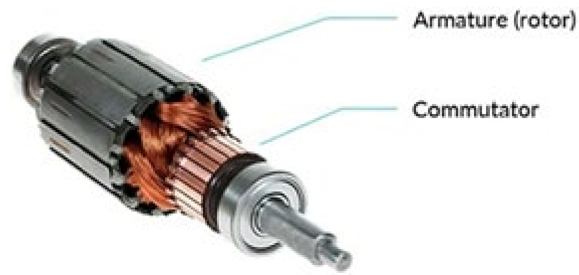

Figure 9. Rotor Design for DC Motor

Engineers refer to the revolving component of a brushed DC motor as the armature. The thin steel disks that are piled on the shaft to carry magnetic flux and lower eddy losses are known as the Lamination stack. Unlike the solid bars of an induction motor, these are actual coils made of copper wire twisted into slots around the stack. One end of the shaft is equipped with copper segments, and it acts as the structure that generates the revolving magnetic field. Field windings or permanent magnets in the stator produce a steady magnetic flux that controls the electric motor's operating efficiency, (Zeineldin et al .2014) . The rotor's dynamic movement, driven by electromagnetic forces, produces the mechanical revolutions needed to drive attached mechanical loads. The rotor is wound with conductive copper coils. Rotors are carefully balanced, and designed for low resistance and friction to guarantee maximum performance, and energy efficiency. The stator's terminals receive electrical electricity, which starts the electromagnetic interaction needed for motor spinning. Every winding end is attached to a steel rod commutator segment, that provides torque to the wheels and gearbox. (Samiulla and Rachananjali 2025)

4. Permanent Magnet Synchronous Motors (PMSMs)

Permanent Magnet Synchronous Motors (PMSMs) are a type of electric motor that uses permanent magnets as both the rotor and a wound stator. Their great efficiency, high power density, and precise control make them popular in many applications, such as robotics, consumer electronics, electric cars, and consumer electronics. Permanent magnet synchronous motors provide several advantages in industrial automation, including high efficiency, high power density, low vibration and noise, precise control, and compact design. Higher price and a shorter speed range are drawbacks. (Gambaretto 2020) .

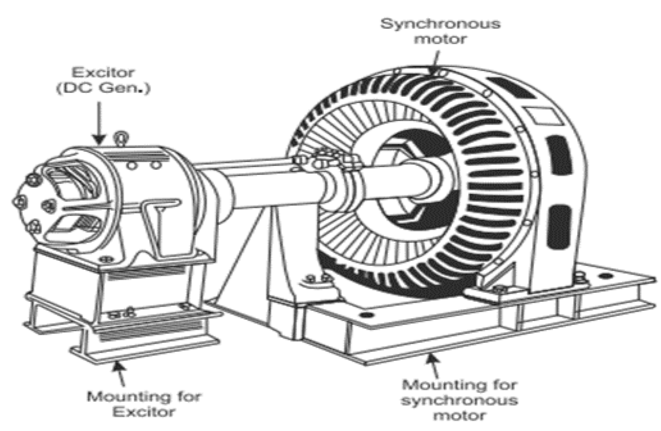

Figure 10. Permanent Magnet Synchronous Motor (PMSM) internal component. (Gambaretto 2020) .

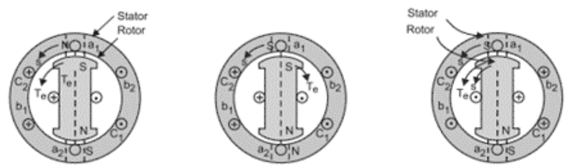

Figure 11. (1) Position of poles at instant t (2) Position of poles after half cycle (3)Position of poles after (Gambaretto 2020, Betz 2024)

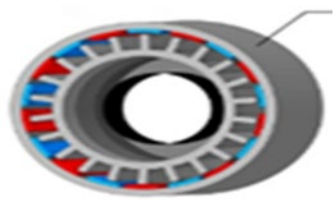

Figure 12. Permanent magnet Synchronous Motor stator design.

The stator design is essential to PMSM performance and Distributed windings are typically used in the primary drive motor of new energy vehicles. Evenly spaced windings optimize the electromagnetic force distribution, effectively suppressing harmonics and improving efficiency and torque output quality. The back electromotive force produced by distributed winding is more accurately controlled, has less electromagnetic noise, and is closer to the ideal sine wave than concentrated winding. By precisely optimizing the winding architecture and electromagnetic force distribution, the stator design greatly enhances noise, vibration and harshness (NVH) performance. High-frequency harmonics can be lowered by up to 30% with the aid of sophisticated electromagnetic field simulation, satisfying customers' demanding standards for silent driving. To optimize the motor's interior space, the small stator structure design may also adapt, flexibly to a range of rotor topologies. (Loganayaki and Kumar 2019, Zhu et al.2019).

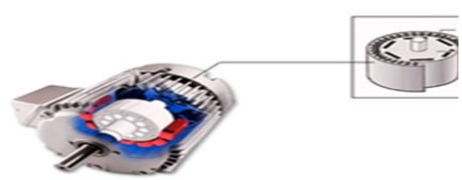

Figure 13. Permanent magnet synchronous motor rotor design (Mohammed and Ezzaldean 2021)

The rotor reduces energy waste by using thin steel sheets layered and embedded in V-grooves to hold the magnets. The permanent magnet synchronous motor's (PMSM) rotor is its central component. This establishes how fast the electric car accelerates and how long it can last. The architecture is similar to the "core gear" of an automobile engine, and with the deft placement of strong magnets, it provides immense power and a silent experience. Simultaneously, the improved design reduces weight and increases acceleration sensitivity. (Loganayaki and Kumar 2019)

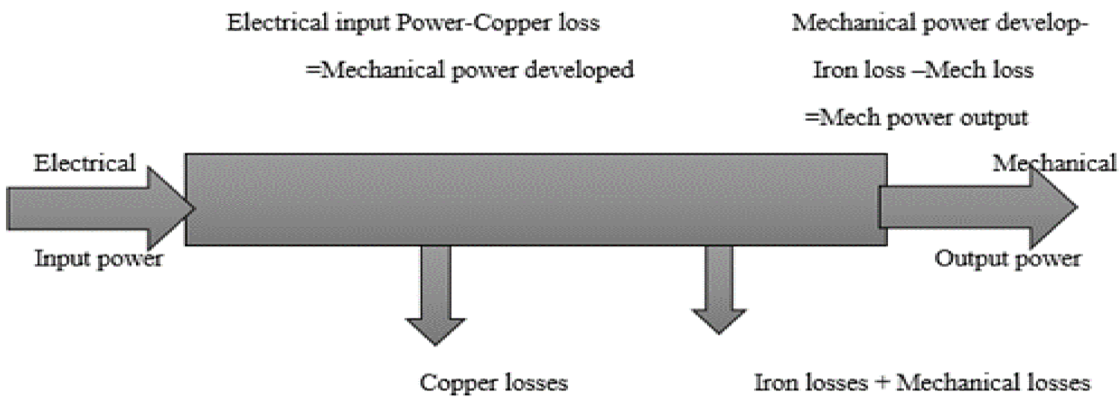

Figure 14. Schematic of a synchronous motor that displays input power, various powers that occur when the machine is operating, and output power

Figure 15 below illustrates the many motor topologies that can be used in electric vehicles.

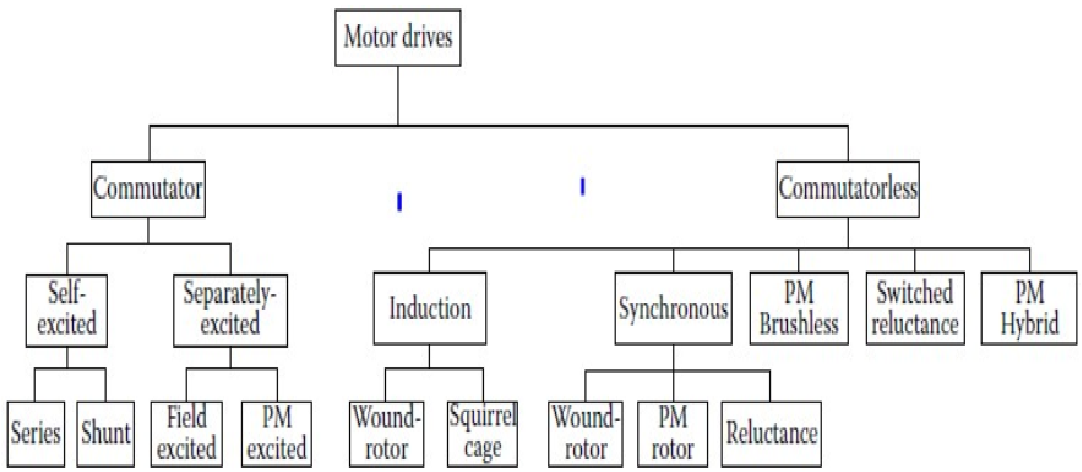

Figure 15. Motor topologies that can be used in electric vehicles (Aminu et al.2019, Soong et al.2021, Samiulla and Rachananjali 2025)

In Figure 7. Greater powertrain flexibility and higher electric machine efficiency when compared to internal combustion engine efficiency when taken as a whole, the aforementioned technologies have the potential to enhance both environmental safety and the electric car system.

Comparison of Induction Motor (IM), DC Motor and Permanent Magnet Synchronous Motor (PMSM) based on criteria (Table 1).

Table 1. Displays comparison of different motor topology based on key criteria.

Motor topologies	Efficiency	Power Density	Torque Ripple	Speed Range	Cost
Induction Motor (IM),	High efficiency, especially with advanced control techniques.	Good power density, but can be improved with advanced designs.	Low torque ripple with advanced control techniques.	Wide speed range with advanced control techniques.	Generally low cost, especially for squirrel-cage designs.
DC Motor	Wide speed range, but efficiency can drop at high speeds.	Moderate power density, often limited by brush and commutator design.	Moderate torque ripple, especially with brushed designs.	Wide speed range, but efficiency can drop at high speeds.	Moderate cost, with brushed designs being less expensive than brushless
Permanent magnet synchronous motor	High efficiency due to permanent magnets and low rotor losses.	High power density due to strong permanent magnets.	Low torque ripple, especially with sinusoidal back-EMF designs.	Wide speed range, with field-weakening techniques enabling high speeds.	Higher cost due to permanent magnets, but decreasing with advancements in magnet

Application Suitability

• Induction Motor IMs: suitable for low-cost, high-speed applications, Industrial drives, electric vehicles, HVAC systems, Fans and pump.

• DC Motors: suitable for low-performance applications, Simple drives, automotive accessories, toys. small EVs and golf carts.

• Permanent Magnet Synchronous Motor PMSMs: suitable for high-performance applications, electric vehicles and robotics.

5. Conclusion

Efficiency, power density, cost, dependability, and control complexity are some of the aspects that influence the motor topology selection for electric vehicle drives. Every motor type has advantages and disadvantages that make it appropriate for particular uses. Induction motors are appropriate for industrial and electric vehicle applications due to their low cost and great reliability. DC motors are straightforward and simple to operate, but their low efficiency and high maintenance needs prevent them from being used in high-performance applications. Unchangeable Magnet Synchronous motors are perfect for high-performance drives and electric cars due to their great efficiency and power density. This comparison makes it easier to choose the best motor for a given application by highlighting the advantages and disadvantages of each motor architecture. It is still necessary to compare the performance of various motor topologies used in electric vehicles and to propose further research for future evaluation of the aforementioned motor topologies.

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