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A review paper on: Comparative Analysis, Characteristic Evaluation and Application for Motors used in Electric Vehicle Propulsion Systems.

Abstract: - Electric vehicles are landscaping the automobile sector with environmental concern and impact of gas emission. This paper describes the need of electric vehicles, components used in the manufacturing and its block diagram interconnection for its working and implementation. The main heart of any electric vehicle is the motor, therefore its selection criteria, technical aspects required to be studied are explained in detail in this review paper. The detailed evaluation of motor selection, technical aspects and latest developments in it are discussed. A comparative analysis of different motors used for electric vehicle propulsion system and their application are reviewed in depth. The review paper provides a detailed comprehensive study of the motors used in the future of vehicle technology i.e. Electric vehicle.

Keywords: Electric vehicle, DC Brushless Motor, Permanent Magnet Synchronous Motor (PMSM), Switched reluctance motor

I. INTRODUCTION TO ELECTRIC VEHICLE

The history of electric vehicles dates to the early 1900s, where they emerged as viable contenders alongside internal combustion engine and steam engine-powered vehicles. At that time, with shorter journeys being more common, the limited range of electric vehicles wasn't as much of a hindrance. However, as the need for vehicles capable of longer journeys became more prevalent,electric vehicles faced challenges. The limited range of early electric vehicles made them less practical for long-distance travel compared to their internal combustion engine counterparts. This factor, among others, contributed to a decline in the popularity of electric vehicles over the following decades. The landscape for electric vehicles began to shift again with growing concerns about environmental protection and the impact of gas emissions on the ozone layer. Governments around the world started implementing policies aimed at reducing emissions from transportation, which led to a renewed interest in electric vehicles.These policies included incentives for electric vehicle adoption, such as tax credits and subsidies, as well as regulations aimed at improving fuel efficiency and reducing emissions from traditional vehicles. Additionally, advancements in battery technology, resulting in increased driving ranges and shorter charging times, made electric vehicles more attractive to consumers.

As a result, electric vehicles have experienced resurgence in recent years, with sales increasing steadily and manufacturers investing heavily in electric vehicle development. This shift towards electric mobility is seen as a crucial step in reducing greenhouse gas emissions and mitigating the impacts of climate change[1].

A vehicle with four motors indeed represents an intriguing concept in electric vehicle design. Having multiple motors can offer several advantages, including improved performance, increased efficiency, and enhanced traction control. Each motor can be independently controlled, allowing for more precise distribution of power and torque to the wheels, which can optimize handling and stability, especially in challenging road conditions. Electric vehicles (EVs) can indeed utilize electric energy as their sole source of power, drawing energy from batteries to drive the electric motors. Alternatively, some EVs use a combination of batteries and gasoline engines, known as plug-in hybrid electric vehicles (PHEVs). In PHEVs, the gasoline engine can either directly power the wheels or serve as a generator to charge the batteries, offering flexibility in driving modes and extended range compared to purely electric vehicles.

The core components of any electric vehicle typically include:

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- Battery: Stores electrical energy and provides power to the electric motor(s) for propulsion. The type and capacity of the battery greatly influence the driving range and performance of the vehicle.
- Electric Motor: Converts electrical energy from the battery into mechanical energy to drive the wheels. There are various types of electric motors used in EVs, such as permanent magnet synchronous motors or induction motors, each with its own characteristics and advantages.
- Controller: Manages the flow of electrical energy between the battery, motor(s), and other vehicle systems. It regulates motor speed and torque based on driver input and vehicle conditions to optimize performance and efficiency.

The figure you mentioned likely illustrates the basic architecture of an electric vehicle, highlighting the integration of these core components. Such diagrams often depict the flow of energy from the battery to the motor(s), as well as the control systems responsible for managing power distribution and vehicle operation.

Overall, electric vehicles represent a diverse and rapidly evolving segment of the automotive industry, with innovations in technology driving improvements in efficiency, performance, and sustainability[2].

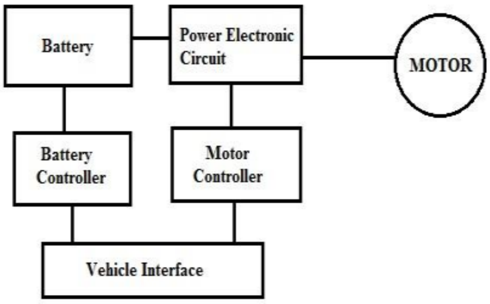

Figure.1 Block diagram of Electric vehicle system.

II. Classification for various Electric Motors used in Electric Vehicles

The electric vehicle system uses different motors, the detailed evaluation is as follows[2]:

1. DC Brushless Motor

BLDC motors indeed offer a range of advantages over traditional brushed DC motors, making them ideal for various applications, particularly in electric vehicles and other high-performance system[2]. The characteristics and applications of both types of BLDC motors are explained as follows.

1.1. Out-runner Type BLDC Motor:

Design aspects has rotor which is positioned outside the stator, which is the opposite of conventional motor designs. Advantages are Compact Design, as the motor is directly connected to the wheel (hub motor), it eliminates the need for an external gear system, reducing overall bulkiness and simplifying the vehicle design and space Efficiency with the elimination of the gear system and the external mounting space required for the motor contributes to a more streamlined vehicle design.

Applications has electric Cycles with Manufacturers like Hullikal, Tronx, and Spero utilize these motors due to their compact design and efficient power delivery. It as includes Two-Wheelers with Companies such as 22 Motors and NDS Eco Motors prefer this type of motor for their electric two-wheelers, benefiting from its space-saving design and performance[3].

1.2. In-runner Type BLDC Motor:

Design aspects include the rotor is positioned inside the stator, similar to conventional motors, requiring an external transmission system for power transfer. Advantages consists with Versatility,while bulkier than out-runner motors due to the need for a transmission system, in-runner motors offer flexibility in design and application.

Applications include three-Wheelers with manufacturers like Goenka Electric Motors, Speego Vehicles, and Kinetic Green utilize BLDC motors for their three-wheelers, benefiting from their performance and efficiency. Other application include low and Medium Performance Scooters vehicles which require reliable propulsion, making BLDC motors a preferred choice for manufacturers seeking efficiency and performance.

In summary, both out-runner and in-runner types of BLDC motors have distinct advantages and applications. Out-runner motors excel in compactness and simplicity, making them ideal for applications like electric cycles and two-wheelers, while in-runner motors offer versatility and are commonly used in three-wheelers and low to medium-performance scooters where the transmission system can be accommodated[3].

2. Induction (Asynchronous) Motor

Factors like high efficiency, good speed regulation and absence of commutator make three phase induction motors widely used in electric vehicle. Three phase AC supply is connected to stator winding, due to which revolving magnetic field is established. This revolving magnetic field interacts with stationary rotor conductors, and induced current flows through rotor conductors. Induced current establishes its own magnetic field. Interaction between revolving magnetic field and field due to induced currents gives rise to unidirectional torque . As speed of rotor is different (less) than speed of revolving field (synchronous speed), these motors are also called as asynchronous motor.

3. Permanent Magnet Synchronous Motor (PMSM)

Permanent magnet synchronous motor is also similar to BLDC motor which has permanent magnets on the rotor. Similar to BLDC motors these motors also have traction characteristics like high power density and high efficiency. The difference is that PMSM has sinusoidal back EMF whereas BLDC has trapezoidal back EMF. Permanent Magnet Synchronous motors are available for higher power ratings. Permanent Magnet Synchronous Motors (PMSM) have indeed emerged as a top choice for high-performance applications in vehicles such as cars and buses. Despite their higher cost compared to induction motors and BLDC motors, PMSMs offer several advantages that make them a preferred option:

1.Increased Efficiency: PMSM motors typically exhibit higher efficiency compared to induction motors, making them more attractive for applications where energy conservation and performance are paramount. The use of permanent magnets in the rotor enhances the motor's efficiency by reducing losses associated with rotor resistance and magnetic field generation.

2.High Performance: PMSM motors offer excellent performance characteristics, including high torque density, fast response times, and precise speed control. These attributes are crucial for achieving optimal performance in vehicles, especially during acceleration, deceleration, and dynamic driving conditions.

3.Competitive Advantage: Despite their higher cost, PMSM motors are providing stiff competition to induction motors due to their superior efficiency and performance. As advancements in motor technology continue to drive down costs and improve efficiency, PMSMs are becoming increasingly competitive in the market.

4.Widespread Adoption: Many automotive manufacturers have adopted PMSM motors for their hybrid and electric vehicles, leveraging their benefits to enhance overall vehicle performance and efficiency. Vehicles such as Toyota Prius, Chevrolet Bolt EV, Ford Focus Electric, Nissan Leaf, Honda Accord, BMW i3, and Zero Motorcycles S/SR utilize PMSM motors for propulsion, showcasing their widespread adoption in the automotive industry.

In summary, PMSM motors offer a compelling combination of high performance, efficiency, and reliability, making them an ideal choice for high-performance applications in vehicles like cars and buses. Despite their higher cost compared to other motor types, the benefits they offer justify their use in hybrid and electric vehicles, where performance and efficiency are critical factors.

4. Switched Reluctance Motor (SRM)

Switched reluctance motor produces torque by variable reluctance method. When stator coils are energized, variable reluctance is set up in the air gap between the stator and the rotor. Rotor tends to move to a position of least reluctance thus causing torque. Switched Reluctance motor has characteristics like high starting torque, wide speed range and good inherent fault-tolerance capability, which makes it suitable for electric vehicle application. Some parameters that must be taken into account while comparing above motors for choosing a best suited motor for required electric vehicle application are power-to-weight ratio, torque-speed characteristics, efficiency, cost of controller, cost of motor.

III. TECHNICAL ASPECTS FOR PARAMETERS OF ELECTRIC MOTORS:

In order to evaluate the parameters of electric motors the technical aspects are explained as below[4].

1. Power-to-Weight Ratio:

Power-to-weight ratio for electric motors is usually calculated using the peak power of motor. Power-to-weight ratio for an electric motor is obtained by dividing the peak power output of motor in KW by weight of motor in Kg. Unit of power-to-weight ratio of motor is KW/Kg. A motor with higher power-to-weight ratio is more suitable for EV application. Same type of motor with same ratings is designed and manufactured differently by different electric motor manufacturers and hence there can be a slight difference in their weights. Here, we will consider mean weight of motor to calculate their power-to-weight ratios. Now, if we consider different types of electric motors with same power, voltage and speed ratings Table -1 shows the value comparison.

Table1. Power-to-weight ratio comparison of different electric motors:

	Brushless DC motor	Induction motor	Switched reluctance motor	PMS Motor
Power to weight ratio	4.5	3.25	3.25	4.2

2. Torque-Speed Characteristics:

The performance and suitability of an electric motor for a particular application can be decided by its torque-speed characteristics. Torque-speed characteristics are also called as mechanical characteristics.

Torque-speed characteristics of brushless DC motor is more drooping than that of DC shunt motor .Torque-speed characteristics of an induction motor slightly differ with different values of rotor resistance. Due to presence of breakdown torque, constant power operation is limited in induction motor. Torque-speed characteristic for medium value of rotor resistance is as shown in Figure-1 below[5].

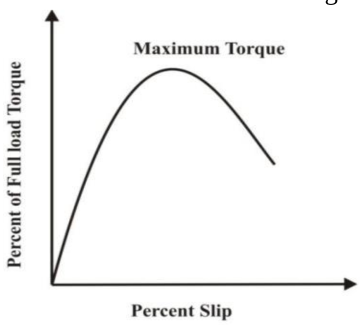

Figure-2. Torque slip characteristics of three phase Induction Motor

PMS motors have torque –speed characteristics as shown below having narrow constant power region. To widen the speed range and increase the efficiency of PMS motors, conduction angle of the power converter can be controlled at speeds higher than the base speed[6].

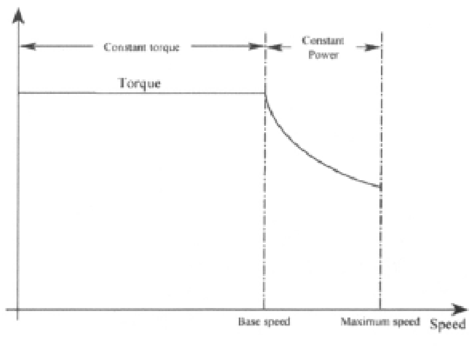

Figure-3 Torque speed characteristics of PMS motor

For switched reluctance motor, torque below base speed is controlled by Pulse Width Modulation (PWM) of current while above base speed torque control is possible only through control of phase turn-on and phase turn-off angles . Torque-speed characteristic of Switched Reluctance Motor is as shown in Figure 3.

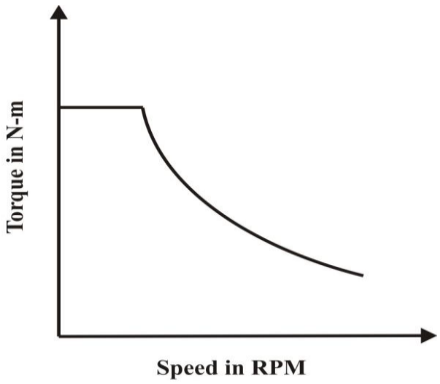

Figure-4 Torque versus speed characteristics of Switched Reluctance Motor

3. Efficiency:

Motor is an electromechanical device which converts electrical energy into mechanical energy. Whole of input electrical energy is not converted into mechanical energy but is lost due to various factors. Electrical efficiency of an electric motor gives us relation between electrical input and useful mechanical output of motor and is generally given by ratio of shaft power output and motor input power . Generally, all electric motors are designed to operate at maximum efficiency at rated output of a motor. When an electric motor is used in electric vehicle, motor will be operated at different loads. Therefore, peak efficiency and efficiency at different loads of a motor must be considered before choosing it for an electric vehicle application. Efficiencies of different electric motors at peak load and at 10% load are tabulated below.

Table-2: Efficiency Comparison of Different Electric Motors

Motor Type	Peak Efficiency (Percent)	Efficiency at 10% load (Percent)
DC brushless motor	>95	70-80
Induction motor	>85	>90
Switched reluctance motor	<95	>90
PMS Motor	>95	>95

4. Cost of Controllers:

Motor controllers are an important part of drive system of an electric vehicle. Motor controller in electric vehicles offers improved performance, efficiency and controllability. If an electric vehicle manufacturer wants to build a low cost electric vehicle, then choosing a low cost controller would eventually affect his choice for motor. For low voltage electric motor widely used in electric vehicle, cost of controllers of different electric motors with same voltage and output power ratings, is as shown below on the scale of 1-5.

Table-3: Comparison for cost of controller

	Brushless DC motor	Induction motor	Switched reluctance motor	PMS Motor
Cost of controller	5	3	3.5	4

5. Cost of Motors:

One of the important challenges ahead of electric vehicle manufacturers is to provide consumer with an electric vehicle which is as good as gasoline vehicle but within an affordable price. Cost of different electric motors with same voltage and output power ratings are compared as shown below on the scale of 1-5.

Table-4: Comparison for cost of motors

	Brushless DC motor	Induction motor	Switched reluctance motor	PMS Motor
Cost of motor	4.5	2	3	4

IV. COMPARATIVE ANALYSIS OF DIFFERENT MOTORS USED IN ELECTRIC VEHICLE PROPULSION SYSTEMS

Comparing different types of motors used in electric vehicle (EV) propulsion systems involves evaluating various factors such as efficiency, power density, torque characteristics, reliability, cost, and suitability for different applications.A comparative analysis of several types of motors commonly used in EVs is as per below Table-5[7]:

Table-5: Comparative analysis

EV Motor	BLDC	Induction Motor	PMSM	SRM
Advantages	High efficiency, low maintenance (no brushes), smooth operation, good power-to-weight ratio. Minimum router heat generation	Robust construction, low cost, suitable for high-power applications. Minimum cost of maintenance	High efficiency, high power density, excellent torque control, regenerative braking capability.	Simple construction, high reliability, low maintenance, good performance at high speeds. Thermal ability enhancing Brushless motor with no magnet
Disadvantages	Complex control electronics, higher initial cost.	Lower efficiency compared to some other types, less torque control at low speeds.	Higher cost	Non-linear control characteristics, limited availability
Suitability	Mainstream EVs, hybrid vehicles, where efficiency and performance are paramount.	Large electric vehicles, industrial applications, where cost is a primary concern.	Mainstream EVs, high-performance electric vehicles, where precise torque control and regenerative braking are essential.	EVs requiring robust, reliable propulsion systems, high-speed applications.

V. CHARACTERISTIC EVALUATION OF MOTORS

The torque and power characteristics of electric vehicles (EVs) are crucial for understanding their performance and efficiency. In Figure 5, which is a graphical representation, we observe that the torque remains relatively constant within a narrow range at low speeds, while the power output extends over a wider range at higher speeds.

This behaviour is typical in EVs and is derived from fundamental aspects of their power source (typically batteries or fuel cells) and transmission systems. At low speeds, the torque remains relatively constant to ensure adequate acceleration and driveability. As the speed increases, the power output becomes more critical, resulting in a wider constant power region where the torque decreases with increasing speed to maintain a consistent power level.

This characteristic is a result of the motor's design and the control algorithms implemented in the vehicle's powertrain. It ensures efficient operation across a range of speeds, optimizing both acceleration and cruising performance while maximizing the vehicle's range.

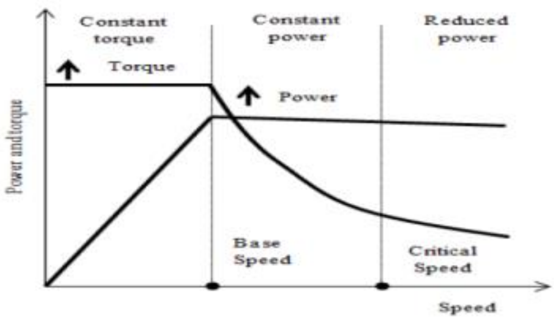

Figure 5- Ideal characteristics of Electric Vehicle.

The listed requirements for EV propulsion systems are comprehensive and essential for ensuring optimal performance and efficiency. Let's break down each requirement:

- High power density and high instant power: This ensures that the propulsion system can deliver sufficient power output for acceleration and dynamic driving situations, such as overtaking or merging onto highways.
- Fault tolerant: The system should be able to continue operating reliably even in the presence of faults or failures, enhancing the overall safety and reliability of the vehicle.

- High power requirement at high speed for cruising: This requirement ensures that the propulsion system can sustain high speeds efficiently, allowing for comfortable and efficient highway cruising.
- High torque requirement for starting and climbing at low speeds: Adequate torque at low speeds is essential for enabling smooth acceleration from standstill and for overcoming inclines or obstacles.
- High efficiency over a range of torque and speeds: Efficiency across various operating conditions ensures optimal energy utilization and extends the vehicle's range on a single charge.
- Fast torque response: Swift response to driver inputs enhances the vehicle's agility and responsiveness, contributing to a better driving experience.
- High efficiency even for regenerative braking: Regenerative braking systems should efficiently convert kinetic energy back into electrical energy during deceleration, maximizing energy recovery and extending the vehicle's range.
- High robustness and reliability for adverse conditions: The propulsion system should withstand harsh environmental conditions and varying terrain, ensuring consistent performance and durability under diverse operating conditions.
- Optimal cost: Balancing performance, efficiency, and cost is crucial to making electric vehicles accessible to a wider market and ensuring their competitiveness against conventional vehicles.
- High torque requirement for starting and climbing at low speeds: This requirement is reiterated to emphasize the importance of torque at low speeds for essential driving maneuvers, such as starting from a stop or navigating steep inclines.

By fulfilling these requirements, EV propulsion systems can deliver the performance, efficiency, and reliability necessary for widespread adoption and acceptance of electric vehicles as viable alternatives to traditional internal combustion engine vehicles.

1. BLDC

The absence of brushes in Brushless DC (BLDC) motors is one of their defining features and advantages. Instead of relying on mechanical commutation through brushes, BLDC motors utilize electronic commutation to convert electrical energy into mechanical energy efficiently.

BLDC motors have gained significant traction in electric vehicle (EV) propulsion systems due to several reasons:

High efficiency: BLDC motors are known for their high efficiency, as they minimize energy loss associated with friction and brush wear. This efficiency contributes to extending the vehicle's range and improving overall performance.

Low maintenance: Without brushes to wear out, BLDC motors require minimal maintenance compared to brushed motors, reducing downtime and maintenance costs over the motor's lifespan.

Compact and lightweight: BLDC motors are typically more compact and lightweight than brushed motors, making them ideal for integration into EVs where space and weight considerations are critical.

Smooth operation: The electronic commutation in BLDC motors allows for precise control of speed and torque, resulting in smoother and quieter operation compared to brushed motors.

Regenerative braking: BLDC motors can easily facilitate regenerative braking, where kinetic energy is converted back into electrical energy during deceleration, improving energy efficiency and extending the vehicle's range.

Overall, BLDC motors have emerged as leading contenders in EV propulsion systems due to their efficiency, reliability, and suitability for demanding automotive applications. Their brushless design offers numerous advantages over traditional brushed motors, making them a preferred choice for electric vehicle manufacturers striving for optimal performance and sustainability[1].

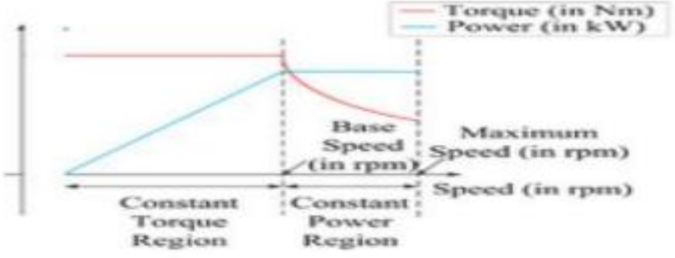

Figure 6- Characteristics of BLDC motor.

2. Induction Motor

Three-phase induction motor highlights its several advantages over other types of motors, particularly in industrial and commercial applications. Here's a breakdown of the key points:

Reliability: Three-phase induction motors are known for their robustness and reliability, making them suitable for continuous operation in various industrial settings.

Ability to work in adverse environments: These motors can withstand harsh conditions such as dust, humidity, and high temperatures, making them versatile for use in a wide range of environments, from factories to outdoor applications.

Less maintenance: Due to the absence of commutator brushes, which are prone to wear and tear, induction motors require minimal maintenance compared to brushed motors. This results in reduced downtime and cost savings over the motor's lifespan.

Low cost: The absence of commutator brushes not only reduces maintenance costs but also contributes to lower overall manufacturing costs, making three-phase induction motors a cost-effective solution for many applications.

In operation, three-phase AC power is supplied to the stator windings, creating a rotating magnetic field. This magnetic field rotates at the synchronous speed in the air gap between the stator and rotor. As a result, currents are induced in the rotor bars due to electromagnetic induction.

These induced currents in the rotor conductors generate a magnetic field in the rotor itself. The interaction between the rotating magnetic field in the stator and the induced magnetic field in the rotor causes the rotor to rotate. Importantly, the speeds of the two magnetic fields, while very close, are slightly varied, creating the necessary torque to drive the motor.

This process allows the induction motor to convert electrical energy into mechanical energy efficiently, making it a widely used and versatile option in various industrial and commercial applications.

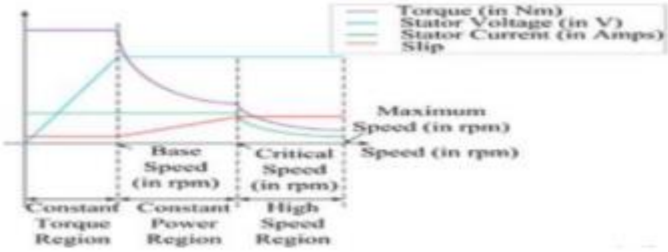

Figure 7- Characteristics of Induction Motor.

3. PMSM

The torque-speed curve of a Permanent Magnet Synchronous Motor (PMSM) used in Electric Vehicles (EVs) provides crucial insights into its performance characteristics. The detailed study of the motor is explained as follows[8].

Constant torque region: In this region, the motor operates below its rated speed, and a constant torque is exerted. This means that regardless of the speed, the motor can maintain a consistent level of torque output. This feature is particularly useful during acceleration and low-speed driving scenarios.

Rated speed: Once the speed of the motor reaches its rated speed, the torque starts to decrease proportionally. This marks the transition from the constant torque region to the constant power region.

Constant power region: In this region, the motor operates at a constant output power. As the speed increases beyond the rated speed, the torque decreases proportionally to maintain this constant power output. This characteristic is essential for sustaining high-speed cruising while ensuring efficient power utilization.

High-speed region: Beyond the constant power region, the torque reduces proportionally with the square of the speed. This indicates that as the motor operates at even higher speeds, the torque decreases rapidly, leading to diminishing acceleration capability.

Understanding these characteristics is crucial for designing the motor control algorithms and optimizing the overall performance of the electric vehicle. By efficiently utilizing the torque-speed curve, engineers can ensure smooth acceleration, high-speed performance, and energy efficiency across a range of driving conditions.

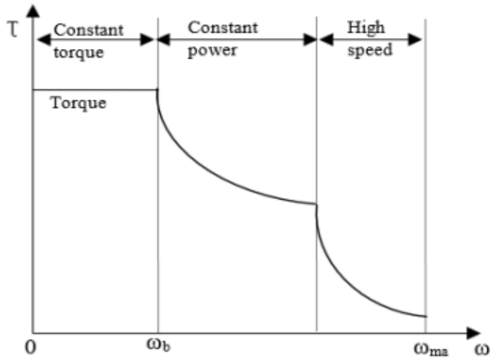

Figure 8- Characteristics of PMSM motor.

4. Switched Reluctance Motors (SRMs)

Improved power density and efficiency: SRMs offer enhanced power density compared to conventional motors, along with good efficiency. This makes them attractive for various applications where space and energy efficiency are crucial[8].

Simple construction: SRMs feature a straightforward construction with concentrated stator windings and no rotor windings. This simplicity contributes to cost-effectiveness and ease of manufacturing.

Challenges in control: While SRMs have advantages in power density and efficiency, controlling them can be more complex due to highly non-linear characteristics, especially in identifying the current switching angles. This complexity poses challenges for precise motor control compared to other three-phase machines.

Torque-speed characteristics: The torque-speed characteristics of SRMs, as shown in Fig. 5, are influenced by the rotor position. The switching of current in the stator winding occurs based on the rotor position, affecting the motor's performance across different operating conditions.

Base speed (ωb): In SRMs, base speed refers to the maximum speed at which maximum current (Imax) can be provided to the motor at rated voltage, with fixed switching angles. This parameter is crucial for understanding the motor's operational limits and designing control strategies.

Synchronization of battery and IC engines: Fig. 8 illustrates the synchronization between battery and internal combustion (IC) engines at different speeds. Depending on speed changes, the battery and IC engine can operate jointly or separately to optimize steady-state and starting performance. This coordination is essential for hybrid electric vehicles to achieve efficient power delivery and propulsion under varying driving conditions.

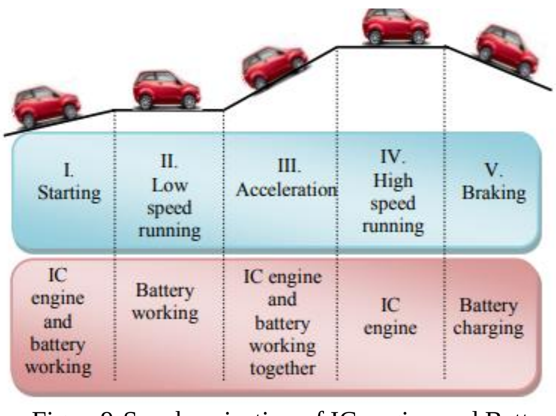

Figure9-Synchronization of IC engine and Battery

Overall, SRMs offer a promising alternative in power electronics applications, but their control complexities and unique characteristics require careful consideration in design and implementation. Efficient control algorithms and synchronization strategies are essential for harnessing the full potential of SRMs in various industrial and automotive applications.

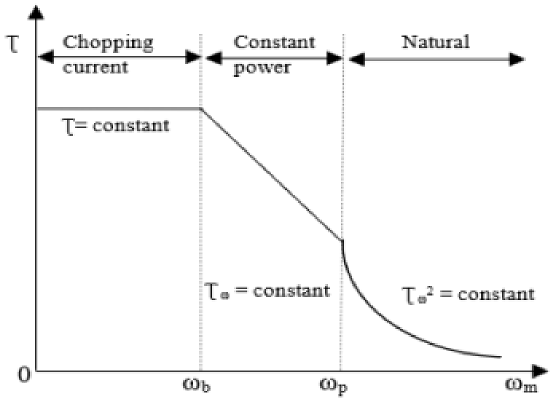

Figure 10- Characteristics of SRM Motor.

VI. Applications

It's clear that electric vehicles (EVs) rely on various types of electric motors to meet different power requirements and performance criteria. The motors used as explained as[4]:

1.Induction Motors (for advanced power):

- Characteristics: Robust, efficient, suitable for high-power applications.
- Common Applications: EVs requiring advanced power capabilities, often used with vector drives for acceleration and torque management.

2.Brushless DC (BLDC) Motors:

- Characteristics: High efficiency, low maintenance, precise control.
- Common Applications: Low-power EVs where efficiency and control are essential, such as electric scooters, bikes, or small city cars.

3.Permanent Magnet Brushless Motors:

- Characteristics: High efficiency, high power density, precise control.
- Common Applications: Mainstream EVs, high-performance electric vehicles where power and efficiency are critical.

4.Switched Reluctance Motors (SRMs):

- Characteristics: Simple construction, robust, reliable.
- Common Applications: EVs requiring robust and reliable propulsion systems, high-speed applications.

Table-6 likely provides a comparison of these motor types based on various parameters such as efficiency, power output, control mechanisms, and suitability for different EV applications. Evaluating these characteristics can help EV manufacturers determine the most appropriate motor type for their specific vehicle requirements, considering factors like performance, cost, and energy efficiency. Additionally, ongoing research into battery improvements, such as advancements in lithium-ion battery technology, continues to influence the design and performance of electric vehicles, further enhancing their capabilities and driving range[9].

Table-6: Comparison of motors on Power (kW) ,type and year of manufacturing

Electrification Model	Power (kW)	Motor Type	Year
My Car	30	BLDC	2003
Smart	30		2009
Morgan Plus E	70		2011
Genkan Electric Motors	1		2013
BYD E6	160		2014
Kinetic Green, Volta Automotive	3.3		2017
Honda e	100		2020
Roadster	215		2008
Tesla Model S	225		2012
Tesla Model X	193-375		2015

Mercedes Benz EQC	300	IM	2016
Toyota Prius	82	PMSM	2004
Lexus	110		2008
Camry	270		2013
NIO EC6	320		2020
Renault kwid	50		2020
Audi e-tron	370		2021
Kia Niro EV	150		2022

VII. CONCLUSION

In this paper, comparison of four different electric motors for electric vehicle application on different criterions like power-to-weight ratio, torque-speed characteristics, efficiency, cost of controller and cost of motor. Comparative evaluation indicates that BLDC motor has small size, higher power-to-weight ratio, but its maintenance cost and cost of controller is high due to expensive control requirements.Three phase induction motor provides efficiency more than 90% at peak load as well as at 10% load. Three phase induction motor and BLDC motor are the two most widely used motors by electric vehicle manufacturers. PMS motors have higher power density, higher efficiency and the more effective distribution of heat into the environment. PMS motors are the most serious competitor to the induction motors in traction applications. Actually, many car manufacturers (such as Toyota, Honda and Nissan) have already used these motors in their vehicles. Switched Reluctance motor provides a great alternative to induction motor and BLDC motor with lower cost of motor and controller, high efficiency at peak load as well as at 10% load, reliability and fault tolerance capability.

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