International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 11 | Nov - 2024 SJIF Rating: 8.448 ISSN: 2582- 3930

COMPREHENSIVE REVIEW ON DIFFERENT MOTORS FOR ELECTRICAL VEHICLES

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ABSTRACT:
The increased demand for electric vehicles requires an accurate choice of electric motor to achieve maximum performance, efficiency, and sustainability in EVs. This is a comprehensive review of five leading types of EV motors: Permanent Magnet Synchronous Motors (PMSM), Induction Motors (IM), Brushless DC Motors (BLDC), Switched Reluctance Motors (SRM). The following review compares a range of motor features related to power density, efficiency, torque density, thermal management, cost-effectiveness, noise, vibration, and reliability. Analysis in the past has indicated trade-offs between motor types and areas for further improvement. Future research directions mainly revolve around advanced materials, innovative designs, and control strategies in optimizing EV motor performance.

Keywords: Electric Vehicles, Electric Motors, Sustainable Transportation, Motor Comparison, Performance, Efficiency.

1. INTRODUCTION *(Size 11, Times New roman)*

Today, the trend toward electric vehicles (EVs), which are alternative solutions, is increasing, due to the fact that internal combustion engine vehicles increase carbon emissions, and countries remain dependent on oil-importing countries. Main components of electrical vehicles as shown in fig1. Unlike traditional ICVs, EVs use electric motors instead of internal combustion motor to offer several outstanding features such as wide-torque speed, high power density, higher efficiency, longer range, reduced maintenance costs, and reduction in air pollution.

The selection of an electric motor itself plays a very important role to increase the driving range and provide high performance along with efficiency in electric vehicles. Main key

features coming forward in the selection of motors used in electric vehicles are simplicity of design, high power density, low maintenance cost, and easy controllability [1]. In electric vehicles, different types of electric motors are used: DC motor, brushless DC motor (BLDC), induction motor (IM), permanent magnet synchronous motor (PMSM), and switched reluctance motor (SRM).A lot of works have been done to improve the performance of electric motors, such as using a high energy permanent magnet materials and semiconductor switches to achieve electronic commutation [1].

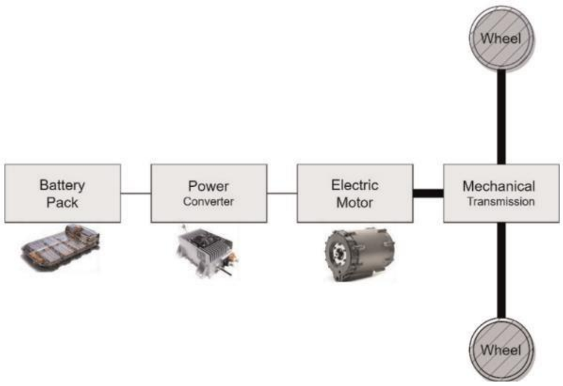

Fig1: Main components of Electrical vehicles

Although DC motors require easy speed control and provide high torque at low speed, but use in EVs applications has decreased due to their low efficiency and require frequent maintenance. On the other hand, the SR motors are still evolving for EVs applications. Induction motors and PMSM motors are the most widely used motors in EVs applications. In spite of induction motor is very matured and reliable with low maintenance costs and the cost is low. This makes the PMSM motors more convenient for use in EVs applications and yields the best performance in terms of high efficiency, high power density, highly reliable, small in size, high torque at low speed and high dynamic response due to the application of high energy. permanent magnet materials such as samarium-cobalt. the performance of motors depends mainly on vehicle duty cycle, thermal characteristics and the cooling mechanism implemented [2].
The reducing price of these permanent magnet materials and the developing of very fast semiconductor switches such as metal oxide semiconductor field effect transistors (MOSFETs) has made the PMSM motors more attractive for EVs applications [2],[3]. In this work, the performance and characteristics of the electric motors which are currently used in EVs applications have been compared and evaluated according to the requirements of an EV propulsion system. Also, conclusion has been made to identify the electric motor which offers the best performance for electric EVs.

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2.TYPES OF ELECTRICAL MOTOR DRIVES

There are the following seven different technologies currently available for EV propulsion.

- DC motors
- Induction motors
- BLDC motors
- PMSM Motors
- SR Motor

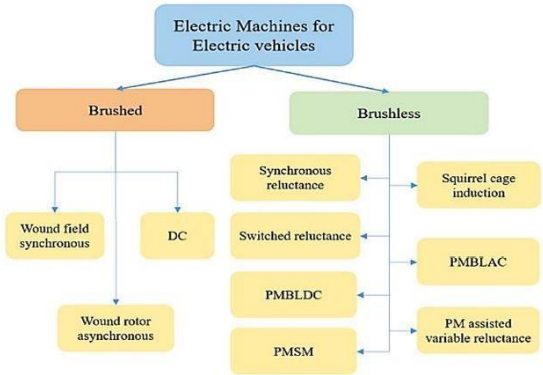

Fig:2 Classifications of motors

3. DC motors

DC motors consist of a stator with a stationary field and a wound rotor with a brush commutation system. The field in the stator is generally induced by coils although small machines may have a permanent magnet excitation. The field winding may be series or shunt connected with the rotor coils depending on the required characteristics as shown in the fig3. The commutator is made up of a set of copper segments, inducing more friction than slip rings and consequently producing dust.[3]

The main advantages of this type of motors are: the technology is well established, reliability, inexpensive and have a simple and robust control. DC motors were the preferred option in variable speed operation applications before the development of advanced power electronics.[3]

Thus, the best type of dc motor is the dc series motor because of its high starting torque. This type has the torque-speed characteristics as shown in fig4. A high torque is achievable at low speeds, but the other way round at high speeds, which is easily understandable [3]. Further this demagnetization of the motor magnetic field caused by armature reaction effect can be compensated by increasing field.

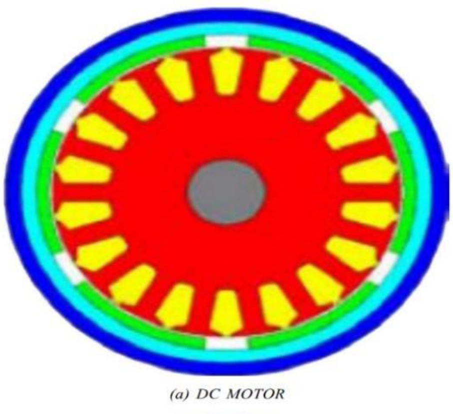

Fig:3 DC MOTOR

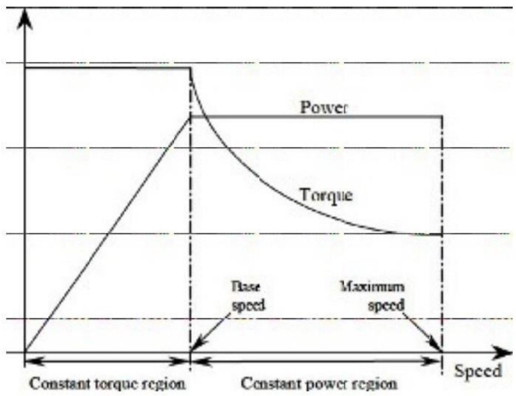

Fig:4 DC motor torque speed characteristics

These motors primary drawbacks are their poor power density, inefficiency, and frequent coal brush repairs (every 3000 h). DC motors are Extremely costly because their size cannot be reduced without significant effort. Furthermore, the brushes and commutator generate friction, which limits the speed. How quickly the motor will reach the limits of breakdown torque. If you run the motor above critical speed and at max current, the motor will hit it is known as breakdown torque and stall.as shown in fig4. Therefore, the breakdown torque limits the motor operation to constant power region. Increased breakdown torque, causes the constant power area to expand slightly. DC motors still have a wide market of lower and middle power range commutation vehicles.

4. PMBLDC Motors

The brushless DC (BLDC) motors are the most popular and widely used in control application and are configured into single-phase, 2-phase and 3-phase as shown in fig5. One major advantage of BLDC is enhanced speed versus torque characteristics as compared with other electric motors. This motor is built with a permanent magnet rotor and wire-wound stator poles [4]. The stator windings work with the permanent magnets on the rotor to generate a uniform flux density in the air gap [4]. This permits the stator coils to be driven by a constant DC voltage (hence the name brushless DC)

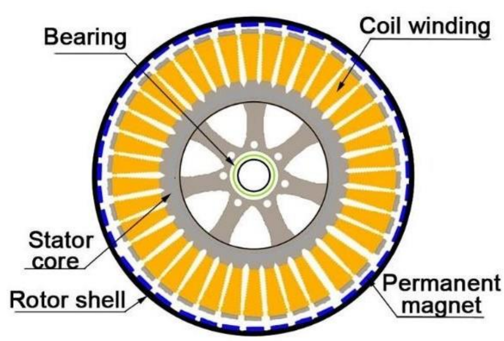

Fig5: BLDC motor

BLDC motor has a permanent magnet rotor surrounded by a wound stator. The AC currents feeding into the stator winding are of rectangular form [4]. The winding in the stator gets commutated electronically, instead of with brushes and commutator.

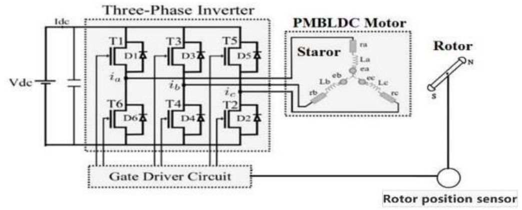

Fig6: Three phase PMBLDC motor drive system

The inverter, gate drive circuit and rotor position sensor realize the electronic commutation as shown in fig6. Based on the signals of the rotor position sensor, the gate drive circuit switches on the switches of the inverter and making the current passes through the stator winding in a particular sequence as shown fig7. As a result of this series of energizing, the PM rotor continues to spin in the clockwise direction and it created the maximum output torque.

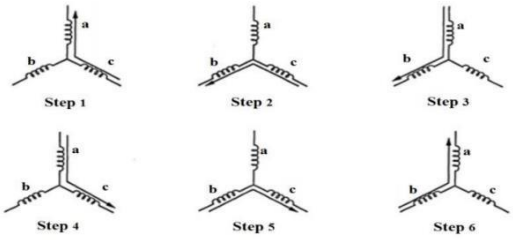

Fig7: Energizing sequence of three phase PMBLDC motor

The BLDC motor offers excellent power density as compared to other motors, higher torque, reduced operational and mechanical noise, elimination of electromagnetic interference and offers excellent efficiency. Hence, this motor is the most popular in EV application [4].

5. PMBLAC Motors (PMSM)

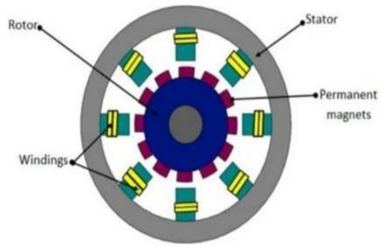

Fig8: PMBLAC Motor

It is similar to the BLDC motor but it is supplied with a sinusoidal signal to get a lower torque ripple [5]. Unlike that of a BLDC motor which generates trapezoidal flux density in the air gap, the sinusoidal distribution of the multi-phase stator windings generates a sinusoidal flux density as shown in fig 9. This motor includes the character of an induction motor and also a brushless dc motor. Those motors have stator winding and rotor with a permanent magnet. Moreover, the stator flux density of the motor is sinusoidal, which is similar to that of the induction motor. This motor has a higher power density than induction motors of the same ratings as none of the stator power is used for producing the magnetic field. These days, these motors are stronger but with a mass and moment of inertia that is lower. The permanent magnet synchronous motor can generate torque from zero speed, very high efficiency, high power density comparing to induction motor. But, this motor doesn't work without a drive. This motor operates with variable frequency drive in order to reach the specifications of high torque at low speed, high density and high efficiency. Although, VFD running method increases complexity of the system which needs to be taken care by accurately controlling the speed. Thus this motor is expensive as compared to the induction motor [5].

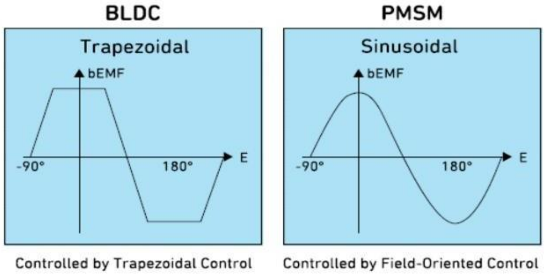

Fig9: EMF wave forms of BLDC&PMSM

In general, due to high torque and power density, good controllability, high torque/inertia ratio and torque/volume ratio, light weight and compactness, PM motors have appropriate characteristics for EV propulsion [6]. These are especially fit for in-wheel direct drive. The PMs lock the main magnetic field in PM motors, so that the power-speed characteristics of PM motors become constant powered over a very limited highspeed range. The speed range can be extended up to 3-4 times the base speed using field weakening. In this scheme, the field weakening operation is achieved by applying a high d-axis demagnetizing current at the maximum sustainable torque-speed point, using some sort of vector control. This would fraise the conductor power loss and demagnetization risk of the PMs as well. In essence, limited resource of rare earth elements and expensive rare earth PMs restricts ubiquitous PM motors for large-scale production cost-sensitive markets including EVs as shown fig10. Japanese PM BL motor drives [5] are common in EVs such as Tino of Nissan, Insight of Honda and Prius of Toyota.

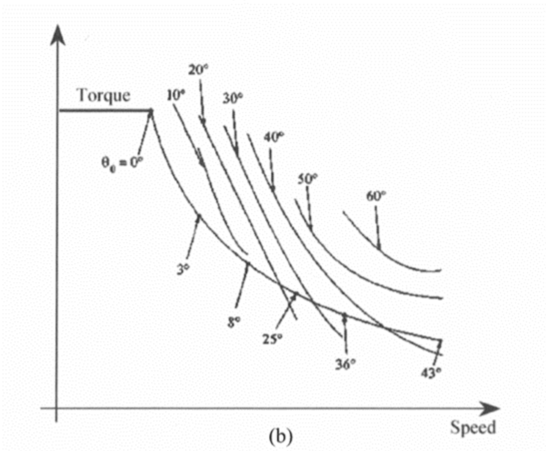

Fig10: Torque-speed characteristic of a PM BLAC(PMSM)

6. Induction motor

Squirrel cage induction motors, in particular, have become a strong candidate for electric vehicle applications because of their remarkable robustness, dependability, low maintenance needs, and capacity to function under harsh conditions. Out of all the competitors of AC, their technology is also the primary features of induction motors are depicted in Figure11. It is noteworthy that vector control techniques can successfully decouple torque and field control. Additionally, flux weakening in the constant power zone enhances the speed range.

Induction motors are not without their drawbacks, despite their benefits. These include rotor windings, which naturally result in poorer efficiency than permanent magnet motors, breakdown torque in the constant power area, decreased efficiency and greater losses at high speeds.[8]

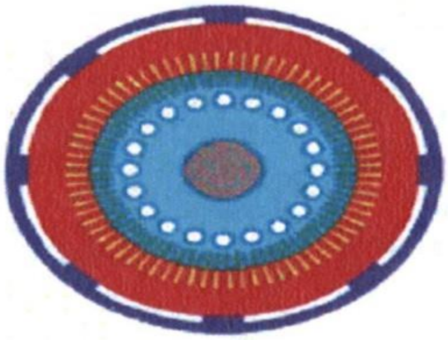

FIG11:induction

However, there are disadvantages to induction motors, such as low power factor, significant energy loss, and inferior efficiency when compared to permanent magnet motors Due to these constraints, rotor losses are reduced by optimized design and multiple inverters are used to provide constant power capabilities, which eventually improves overall performance and efficiency.[9]

Unlike some motors, like the ones in older cars or certain appliances, three-phase induction motors don't have a commutator. A commutator is a part that helps switch the direction of current in the motor. Not having a commutator means the motor is simpler, more reliable, and doesn't need as much maintenance. This makes it great for electric vehicles (EVs), where you want a motor that can run efficiently and for a long time without breaking down.the torque speed characteristics of an induction motor shown fig12.

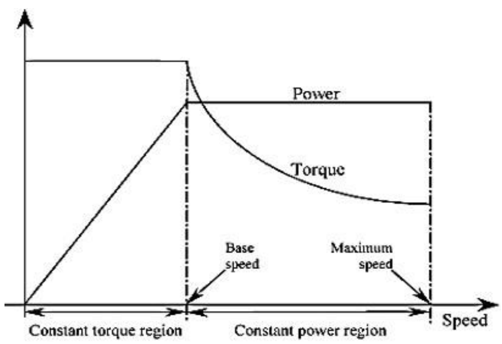

Fig12: torque speed characteristics of an induction motor

7. Switched Reluctance Motors

Switched reluctance motors are becoming more and more popular in HEV systems. These motors fault tolerance, straightforward control, simple and sturdy design, and superior torque-speed characteristics are some of their benefits. A switching reluctance motor can function within a broad, consistent power range by nature. For this motor, a number of drawbacks have been noted, including high noise, high torque ripple, unique converter architecture, and electromagnetic obstruction [10]. The benefits and drawbacks of this motor are significant for EV applications. In the illustration, a typical torque speed characteristic of an SRM is shown fig 13.

The operational principle of Switched Reluctance Motors (SRMs) involves switching between different phases to produce torque, which results in high torque ripple and acoustic noise. This makes SRMs less suitable for applications where smooth operation is crucial. Another major disadvantage of SRMs is their low power factor and high rotor losses, which are caused by high frequency switching of the phases, which generates heat and lowers the motor's overall efficiency[10]. Finally, the low power factor of SRMs can result in increased energy consumption and decreased system efficiency. SRMs limit high-speed capability because of reliability issues and necessitate intricate control systems and advanced power electronics, which raises costs and complexity.

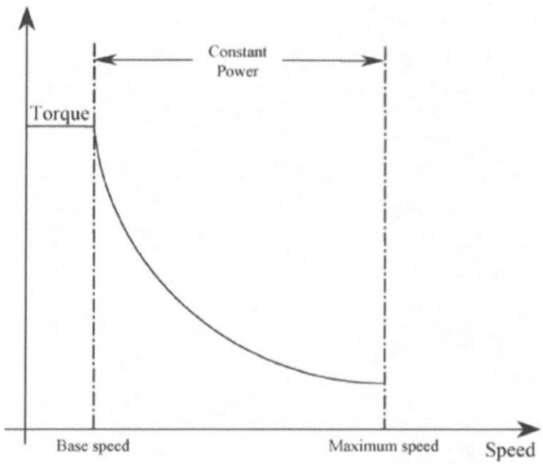

Fig13: switched reluctance motor torque speed characteristics

8. Performance comparison of electric motors

Permanent Magnet (PM) Motors are renowned for their great power density and 95%+ efficiency. They provide a large speed range, excellent torque production, and minimal weight. Due to their small size and low noise level, PM motors are appropriate for EVs.

Switched Reluctance (SR) Motors are inexpensive and have an efficiency of 90% or more. They offer a high torque output and the EVs might benefit from SR motors because of their dependability and minimal maintenance requirements. the comparison table of major electrical motors used in electrical vehicles as shown in fig14.

performance comparison of major electrical motors used in electrical vehicles applications

performance	Dc motor	Induction motor	PMBL DC motors	PMBL AC motors	SR motor
Power density	L	M	H	H	M
Reliability	M	V.H	H	H	V.H
efficiency	L	M	H	H	M
cost	M	L	H	H	M
size	M	M	S	S	La
controllability	V.H	V.H	H	H	M
Speed range	M	M	L	L	H
Maximum torque	M	M	H	H	H

Torque ripple	L	L	M	L	H
Acoustic noise	M	L	L	L	H
Technology maturity	V.H	V.H	H	H	H

L=Low, M=Medium, H=Height, V.H=very high, S= Small, La=large

Fig14. performance comparison of electric motors

CONCLUSION

Advantages and disadvantages of these motors (DC motors, Induction motors, SR motors and PMBL motors) are analysed and evaluated. The main conclusions drawn from this comparative evaluation are: I) PMBL motors are the most energy efficient and they have the highest power density, moreover they have the ability to produce larger torque than other motors at the same values of currents and voltage. However, the use of permanent magnet increases the cost, ii) Induction motors have very high reliability and the most cost effective motors, iii) DC motors are easy to control, but have high maintenance and low efficiency, iv) SR motors can offer long constant power range and high reliability. However, it produces high torque ripple and acoustic noise, v) PMBL motors and induction motor are the most appropriate electric motors for EVs applications and widely found in the EVs market, while DC motors have limited use now days in EVs applications. SR motor is gaining much interest by EVs manufacturers, but still need more researches to improve its characteristics, vi) In this paper many studies and researches about different AI techniques which are used to improve the performance of EVs were presented and it was shown that the intelligent systems are suitable to control and optimize the EVs challenges.

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