Journal of
Thermal Engineering and Applications

ISSN: 2349-8994
Volume 11, Issue 2, 2024
May–August
DOI (Journal): 10.37591/JoTEA

https://journals.stmjournals.com/jotea

Review JoTEA

A Review on Various Types of Motors Used in Electric Vehicles

Arun Kumar Yadav[1,*], Muskan Yadav[2], Sushil Kumar Agrawal[3], Rachit Srivastava[1], Anurag Dwivedi[1], Rajesh Kumar[2]

Abstract

To maintain environmental equilibrium, a "green revolution" is required, as modern society relies excessively on fossil fuels to fund its indulgences. The pursuit of sustainable energy and reducing carbon dioxide emissions from internal combustion engines has motivated scientists and engineers to investigate and create unique driving systems. Vehicle emissions have decreased significantly because of the introduction of hybrid automobiles. Electric vehicles (EVs) rely on various types of motors to convert electrical energy into mechanical power, each with distinct characteristics suited to different applications. This review explores the main motor types used in EVs, including permanent magnet synchronous motors, induction motors, switched reluctance motors, and brushless DC motors. This is insufficient, though. The implementation of entire EVs is crucial as they are completely clean. Consequently, the internal combustion engine seen in ordinary cars and autos is replaced with an electric motor in these vehicles. Therefore, experts in the industry are concerned about the requirement for greatly enhanced motors that can function at their best. This study reviews various electric motors based on their affordability, efficiency, robustness, and ease of design. In conclusion, research has shown that brushless DC motors are the most effective and well-suited option for propulsion drive in both hybrid electric and electric cars. Its control, though, is inadequate. It also presents a theoretical approach to enhance its control.

Keywords: Electric motors, electric vehicle, automobile, brushless DC (BLDC) motor, induction motor (IM), switched reluctance motor (SRM)

INTRODUCTION

We know that the conventional automobiles generate a lot of pollutants into the atmosphere because their engines burn fuel inside, increasing the amount of pollution in the air. Fuel has become more expensive and more in demand [1]. But on the other side, electric vehicles (EVs) are highly efficient, affordable, and environmentally benign, there will be an increasing demand for them in the future. The purpose of this study is to compare several motor types that can be utilized in EVs to maximize their efficiency. DC brushed motor (DCBM), DC brushless motor (BLDC), induction motor (IM), permanent magnet synchronous motor (PMSM), synchronous reluctance motor (SYNRM), and switched reluctance motor are compared in this paper. After review of several motor types, it was discovered that induction motor and permanent magnet brushless DC motor have higher power densities, are more dependable, and efficient than the other motor types covered in this work [2].

***Author for Correspondence**
Arun Kumar Yadav
E-mail: dr.arunkumaryadavee@gmail.com

[1]Assistant Professor, Department of Electrical Engineering, Bansal Institute of Engineering & Technology, Modipuram, Meerut, Uttar Pradesh, India
[2]Student, Department of Electrical Engineering, Bansal Institute of Engineering & Technology, Modipuram, Meerut, Uttar Pradesh, India
[3]Professor, Department of Electrical Engineering, Bansal Institute of Engineering & Technology, Modipuram, Meerut, Uttar Pradesh, India

Received Date: June 04, 2024
Accepted Date: July 09, 2024
Published Date: July 20, 2024

Citation: Arun Kumar Yadav, Muskan Yadav, Sushil Kumar Agrawal, Rachit Srivastava, Anurag Dwivedi, Rajesh Kumar. A Review on Various Types of Motors Used in Electric Vehicles. Journal of Thermal Engineering and Applications. 2024; 11(2): 35–43p.

The future is believed to belong to EVs, so it is essential that we continue researching ways to make them more user-friendly in order to not only enhance the EV adoption rate, but also enhance the international electrification of nations [3, 4]. A crucial component of research is necessary to determine the kind of motor that can supply the best price to performance ratio and the most value.

LITERATURE REVIEW

The EV revolution has spurred significant advancements in electric motor technology [5]. Selecting the most suitable motor for a particular EV application necessitates a comprehensive understanding of the advantages and disadvantages inherent to each type. This review delves into the most prevalent EV motor technologies, exploring their design principles, performance characteristics, and suitability for various EV applications [6].

DC Brushed Motor (DCBM)

- DCBMs (Figure 1) are the simplest type of electric motor, making them relatively inexpensive to manufacture. This has historically positioned them as a popular choice for early EVs [7].
- DCBMs utilize brushes to mechanically commute (switch) current between the rotor and stator. This brush friction creates wear and tear on the brushes, reducing efficiency and requiring periodic maintenance.
- Due to brush friction and sparking, DCBMs generally have lower efficiency and power density compared to other EV motor options [8].

DC Brushless Motor (BLDC)

BLDCs (Figure 2) address the limitations of DCBMs by using electronic controls to manage commutation. This eliminates brush friction, leading to higher efficiency, reduced maintenance requirements, and longer lifespan. BLDCs offer a good balance between performance and cost [9]. Their robust design and affordability make them suitable for a wide range of EV applications, including low- and medium-power EVs, hybrid EVs (HEVs), and plug-in hybrid EVs (PHEVs).

Induction Motor (IM)

- Induction motors (Figure 3) are known for their robust construction and ability to operate in harsh environments. They are relatively inexpensive to manufacture and require minimal maintenance, making them a popular choice for industrial applications [10].
- The operating principle of induction motors results in lower efficiency, particularly at lower speeds. This can be a drawback for EVs in urban environments with frequent stop-and-go traffic.

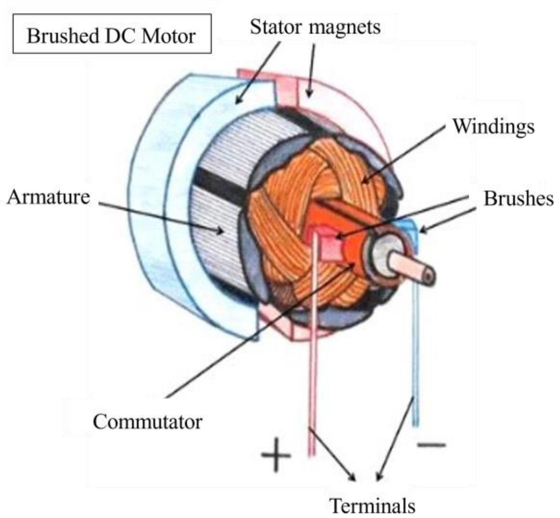

Figure 1. Diagram of DC brushed motor [11].

Figure 2. Diagram of DC brushless motor [12].

Figure 3. Diagram of induction motor [13].

Permanent Magnet Synchronous Motor (PMSM)

- PMSMs (Figure 4) utilize permanent magnets on the rotor to generate a strong magnetic field. This design leads to high efficiency, power density (the amount of power produced per unit of motor weight), and a wide speed range. These qualities make PMSMs ideal for high-performance EVs that require rapid acceleration and excellent overall efficiency [14].

A potential drawback of PMSMs is the reliance on rare earth elements for the permanent magnets. These materials can be expensive and have geopolitical supply chain concerns.

Synchronous Reluctance Motor (SYNRM)

- SYNRMs (Figure 5) offer a lower-cost alternative to PMSMs by achieving reasonable efficiency without permanent magnets. They rely on the inherent magnetic properties of the rotor steel to generate torque [15].

The simpler design of SYNRMS translates to good reliability and potentially lower manufacturing costs compared to PMSMs. However, their torque characteristics may be less favorable than PMSMs, especially at lower speeds.

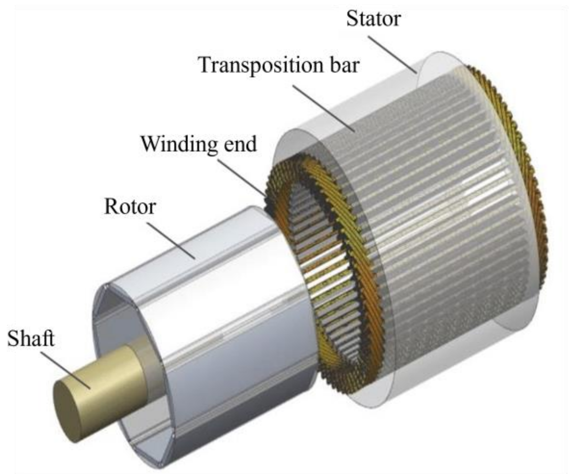

Figure 4. Diagram of permanent magnet synchronous motor [16].

Figure 5. Diagram of synchronous reluctance motor [17].

Switched Reluctance Motor (SRM)

- SRMs (Figure 6) possess a unique design with a segmented rotor and stator that generates torque through the interaction of magnetic reluctance [18]. This design offers high torque density and the potential for low-cost manufacturing due to the absence of permanent magnets and complex windings.
- The torque control of SRMs can be more complex compared to other motor types. Additionally, their operating principle may result in higher noise and vibration levels.

METHODOLOGY

The selection of the optimal electric motor for an EV application is a crucial decision that significantly influences the vehicle's performance, range, efficiency, and overall cost [19]. Various electric motor technologies offer distinct advantages and disadvantages, making a thorough understanding of their characteristics essential for EV engineers. This review will delve into the most common types of electric motors used in EVs, analyzing their design principles, operating characteristics, and suitability for different EV applications.

Motor Selection

DC Brushed Motors

- *Construction:* These motors consist of a cylindrical stator with a fixed magnetic field and a rotating armature (rotor) with windings. The armature windings are connected to a commutator, which is a cylindrical structure with segments of copper separated by insulating gaps. Brushes made of graphite or carbon ride on the commutator, making electrical contact with the armature windings and supplying current to create a magnetic field in the armature [20].
- *Operation:* When current flows through the armature windings, it creates a magnetic field that interacts with the stator's magnetic field, generating torque that causes the rotor to spin. The commutator and brushes are crucial for reversing the current direction in the armature windings as the rotor rotates [21]. This current reversal is necessary to maintain the attractive force between the stator and rotor magnetic fields and keep the motor spinning.

Brushless DC Motors

- *Construction:* These motors eliminate the brushes and commutators of DC brushed motors. Instead, they use permanent magnets mounted on the rotor and windings on the stator [20]. The electronic control unit (ECU) of the motor controls the current in the stator windings using transistors or other switching devices. By rapidly switching the current on and off in the windings according to a specific sequence, the ECU creates a rotating magnetic field in the stator.

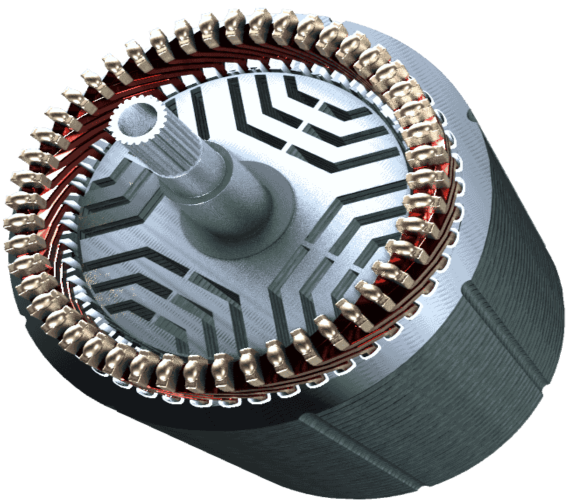

Figure 6. Diagram of switched reluctance motor [22].

- *Operation:* The rotating magnetic field in the stator interacts with the permanent magnets on the rotor, attracting and repelling them to generate torque. The ECU constantly monitors the rotor's position (using sensors) and adjusts the sequence of current switching in the stator windings to maintain a rotating magnetic field that stays synchronized with the rotor's position [23]. This synchronization ensures efficient torque production.

Induction Motors

- *Construction:* These motors consist of a cylindrical stator with windings and a squirrel-cage rotor. The stator windings are connected to an AC power source, which creates a rotating magnetic field in the stator when energized. The squirrel-cage rotor is made of conductive bars (usually aluminum) arranged in a cylindrical cage with conducting end rings at both ends. These bars and rings form a closed loop for current [21].
- *Operation:* The rotating magnetic field in the stator induces eddy currents in the squirrel-cage rotor. These eddy currents interact with the stator's magnetic field, generating a force that tries to oppose the rotation of the magnetic field. However, due to inertia, the rotor cannot perfectly keep up with the rotating magnetic field, and this difference in speed (slip) is what creates torque in the motor. The rotor continues to rotate in the same direction as the stator's rotating magnetic field.

Permanent Magnet Synchronous Motors

- *Construction:* These motors use permanent magnets mounted on the rotor and windings on the stator, similar to BLDC motors. However, unlike BLDC motors, which rely on electronic switching to create a rotating magnetic field in the stator, PMSMs rely on the permanent magnets on the rotor to generate a constant magnetic field [24].
- *Operation:* When the PMSM stator windings are energized with AC current, it creates a rotating magnetic field in the stator. This rotating magnetic field interacts with the permanent magnetic field of the rotor, and since opposite poles attract, the rotor is forced to rotate in synchrony with the rotating stator field. The permanent magnets on the rotor ensure a constant magnetic field, which contributes to the high efficiency and good controllability of PMSMs.

Synchronous Reluctance Motor

- *Construction:* The stator of a synchronous reluctance motor houses the windings, typically distributed around the inner periphery with salient poles (projecting teeth) to create a focused magnetic field. The rotor, on the other hand, is made of ferromagnetic material but unlike a squirrel cage rotor in an induction motor, it does not have any windings. Instead, it has protruding teeth designed with an unequal number of poles compared to the stator. This unevenness creates a path of least magnetic resistance for the stator's rotating magnetic field to interact with.
- *Operation:* When supplied with AC current, the stator windings generate a rotating magnetic field. Initially, the SYNRM relies on a phenomenon similar to induction motors to get going. As the uneven rotor teeth pass near the stator's magnetic field, induced currents are created in the rotor due to a difference in reluctance (magnetic resistance). These induced currents, in turn, generate their own magnetic field that tries to align with the stator's rotating field [25]. This interaction provides the initial torque to get the rotor spinning up to near-synchronous speed (the speed at which the rotor's magnetic field aligns with the stator's rotating field). Once at near-synchronous speed, the reluctance torque takes over. The rotor teeth tend to align themselves with the axis of the rotating magnetic field, minimizing the reluctance path. This alignment-chasing behavior generates continuous torque to keep the motor running.

Switched Reluctance Motors

- *Construction:* These motors have a relatively simple design with a slotted stator and a salient-pole rotor. The stator has windings on each pole, and the rotor has protruding teeth instead of a smooth cylindrical shape [26].

- *Operation:* By rapidly switching the current on and off in the stator windings, the motor creates a magnetic force that attracts the rotor teeth. The current switching sequence is designed so that the magnetic force always tries to pull the rotor teeth into alignment with the energized stator poles. As the rotor teeth move to align with the energized poles, they are repelled by the next set of poles that become energized, causing the rotor to continue rotating.

Components

EVs have unique components compared to gasoline cars. The battery pack stores electricity, and the inverter converts it to power the electric motor. A controller manages the flow, and a charger replenishes the battery. An auxiliary battery supplies power when the main battery is inactive. EVs also use an electric motor and a cooling system to keep things running smoothly [27]. Explanation of the block diagram shown in Figure 7:

- *Battery pack:* Stores the electrical energy that powers the entire EV drivetrain.
- *Battery management system (BMS):* Manages the battery's health and safety, including monitoring voltage, current, temperature, and state of charge (SOC).
- *DC-AC inverter:* Converts the DC (direct current) electricity from the battery pack into AC (alternating current) electricity for the motor. Some motors may be DC motors and not require this conversion, but AC motors are more common in EVs due to their efficiency and controllability.
- *Motor controller:* This electronic unit receives driver input (e.g., accelerator pedal position) and translates it into control signals for the motor. It regulates the current and voltage delivered to the motor, allowing for precise control of speed and torque.
- *Electric motor:* Transforms the AC or DC electrical energy into mechanical rotational energy (torque) that drives the wheels [28].
- *Transmission (optional):* May be used to adjust the gear ratio between the motor and the wheels, optimizing torque and speed for different driving conditions. Not all EVs have transmissions.
- *Differential:* Splits the torque from the motor and distributes it to the left and right wheels, allowing them to rotate at different speeds when cornering.
- *Drive axles:* Shafts that connect the differential to the wheels, transmitting rotational power.
- *Vehicle wheels:* The final point of contact with the road, where the rotational energy translates into the vehicle's movement.

Advantages

- BLDC motors forego brushes, which eliminates friction losses that would otherwise convert electrical energy into heat. This translates to increased efficiency and extended range for EVs, allowing them to travel farther on a single charge [29].

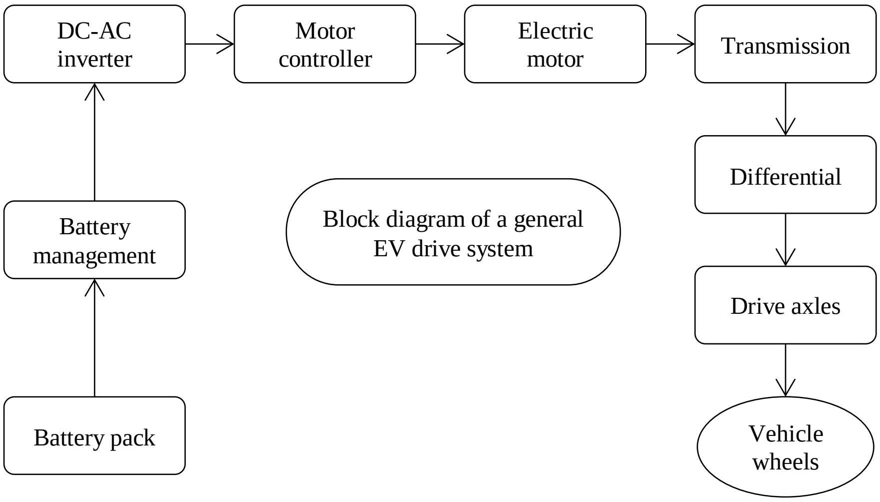

Figure 7. Block diagram of a generic electric vehicle (EV) motor system.

- BLDC motors deliver high power output relative to their size and weight. This translates to a lighter motor for the EV, which can improve overall vehicle efficiency and performance. In EVs where space is limited, a BLDC motor's compact size is a significant advantage.
- The absence of brushes eliminates wear and tear from sparking and friction. This translates to less maintenance and a longer lifespan for the BLDC motor compared to brushed DC motors.
- Without brushes, BLDC motors generate minimal noise, contributing to a quieter and more pleasant driving experience in EVs.
- The simpler design of BLDC motors, with no brushes to wear out, enhances their reliability compared to brushed DC motors.
- Unlike brushed motors that can spark during operation, BLDC motors do not spark. This makes them suitable for environments where flammable gases are present.
- BLDC motors excel at precise speed control, allowing for smooth acceleration and braking in EVs. This can contribute to a more comfortable driving experience and potentially improve regenerative braking efficiency [30].
- BLDC motors can deliver high torque, even at low speeds. This is beneficial for EVs, especially when starting from a standstill or when climbing hills.

Disadvantages

- BLDC motors may not be ideal for applications that require high speeds, such as high-performance EVs. Their torque capability can be reduced at higher speeds, which can affect acceleration and overall performance.
- BLDC motors can generate a significant amount of heat, especially at high speeds. This heat can lead to efficiency losses and reduce the overall range of an electric vehicle. Proper heat management systems are needed to address this issue.
- BLDC motors require complex electronic control systems to operate efficiently. This can add to the cost and complexity of the overall electric vehicle drivetrain.
- BLDC motors use permanent magnets, which can be expensive materials. This can make BLDC motors more costly than some other types of electric motors, such as AC induction motors [31–33].

CONCLUSION

In the arena of EVs, BLDC motors stand out as a compelling choice due to their well-rounded performance. While not without some drawbacks, BLDC motors offer a winning combination of high efficiency, compact size, and lighter weight compared to traditional motors. This translates to extended range, improved acceleration, and potentially lower overall vehicle weight in EVs. Additionally, the brushless design boasts advantages in terms of quieter operation, lower maintenance needs, and potentially reduced long-term costs. While other motor technologies may offer even higher efficiency or specific benefits, BLDC motors strike a balance between performance and affordability, making them a popular selection for powering electric vehicles today. With these advantages, BLDC motors find wide spread applications in automotive, appliance, aerospace, consumer, medical, instrumentation and automation industries. The Indian standard will ensure the quality production of BLDC motors and therefore the ensuring enhanced performance of the appliances using BLDC motors. A highly efficient BLDC motor may substantially reduce the energy consumption of appliances and thereby improving the overall efficiency of appliance.

Future Scope

The future of EVs is bright, and BLDC motors are poised to be a key driver of this progress. Compared to other motors, BLDC motors boast superior efficiency, allowing drivers to travel farther on a single charge – a critical factor for widespread EV adoption. Additionally, BLDC motors offer exceptional control, translating to a smoother driving experience with improved acceleration and regenerative braking, a technology that captures energy during deceleration and puts it back into the battery for extended range. Moreover, the brushless design minimizes friction, reducing maintenance needs and lowering overall ownership costs. While the initial cost might be slightly higher, advancements in manufacturing techniques and material science are expected to bring BLDC motors to cost parity with other options. In essence, the efficiency, controllability, and reliability of BLDC motors make them a perfect fit for powering the next generation of EVs.

REFERENCES

1. de Santiago J, Bernhoff H, Ekergård B, Eriksson S, Ferhatovic S, Waters R, Leijon M. Electrical motor drivelines in commercial all-electric vehicles: a review. IEEE Trans Vehic Technol. 2011; 61 (2): 475–484.
2. Aliasand AE, Josh FT. Selection of motor for an electric vehicle: a review. Mater Today Proc. 2020; 24: 1804–1815.
3. Rind SJ, Ren Y, Hu Y, Wang J, Jiang L. Configurations and control of traction motors for electric vehicles: a review." Chin J Electric Eng. 2017; 3 (3): 1–17.
4. Zarma TA, Galadima AA, Aminu MA. Review of motors for electrical vehicles. J Sci Res Rep. 2019; 24 (6): 1–6.
5. Lulhe AM, Date TN. A technology review paper for drives used in electrical vehicle (EV) & hybrid electrical vehicles (HEV). In: 2015 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT), Kumaracoil, India, December 18–19, 2015. pp. 632–636.
6. Yildirim M, Polat M, Kürüm H. A survey on comparison of electric motor types and drives used for electric vehicles. In: 2014 16th International Power Electronics and Motion Control Conference and Exposition, Antalya, Turkey, September 21–24, 2014. pp. 218–223.
7. Cao W, Bukhari AAS, Aarniovuori L. Review of electrical motor drives for electric vehicle applications. Mehran Univ Res J Eng Technol. 2019; 38 (3): 525–540.
8. Singh KV, Bansal HO, Singh D. A comprehensive review on hybrid electric vehicles: architectures and components. J Modern Transport. 2019; 27 (2): 77–107.
9. Li S. A review of electric motor drives for applications in electric and hybrid vehicles. [Online]. March 2017. ResearchGate. Available at https://www.researchgate.net/publication/330533021_A_Review_of_Electric_Motor_Drives_for_Applications_in_Electric_and_Hybrid_Vehicles
10. Rind SJ, Jamil M, Amjad A. Electric motors and speed sensorless control for electric and hybrid electric vehicles: a review. In: 2018 53rd International Universities Power Engineering Conference (UPEC), Glasgow, UK, September 4–7, 2018. pp. 1–6.
11. Schweber B. Don't ignore the humble brushed DC motor, motor control. [Online]. 2024. Available at https://www.mouser.com/applications/dont-ignore-the-brushed-dc-motor/
12. Gambhir R, Jha AK. Brushless DC motor: construction and applications. Int J Eng Sci. 2013; 2 (5): 72–77.
13. Parekh R. AC induction motor fundamentals. DS00887A. [Online]. 2003. Microchip Technology Inc. Available at https://ww1.microchip.com/downloads/aemDocuments/documents/OTH/ApplicationNotes/ApplicationNotes/00887a.pdf
14. Szalay I, Fodor D, Enisz K, Medve H. Permanent magnet synchronous motor model extension for high-frequency signal injection-based sensorless magnet polarity detection. Energies. 2022; 15 (3): 1131.
15. Rimpas D, Kaminaris SD, Piromalis DD, Vokas G, Arvanitis KG, Karavas C-S. Comparative review of motor technologies for electric vehicles powered by a hybrid energy storage system based on multi-criteria analysis. Energies. 2023; 16 (6): 2555.
16. Liang Y, Zhao F, Xu K, Wang W, Liu J, Yang P. Analysis of copper loss of permanent magnet synchronous motor with formed transposition winding. IEEE Access. 2021; 9: 101105–101114.
17. Matyska P. Advantages of synchronous reluctance motors. Trans Electric Eng. 2014; 3 (2): 44–47.
18. Wahid MR, Budiman BA, Joelianto E, Aziz M. A review on drive train technologies for passenger electric vehicles. Energies. 2021; 14 (20): 6742.
19. Jape SR, Thosar A. Comparison of electric motors for electric vehicle application. Int J Res Eng Technol. 2017; 6 (9): 12–17.

20. Hashemnia N, Asaei B. Comparative study of using different electric motors in the electric vehicles. In: 2008 18th International Conference on Electrical Machines, Vilamoura, Portugal, September 6–9, 2008. pp. 1–5.
21. Bhatt P, Mehar H, Sahajwani M. Electrical motors for electric vehicle – a comparative study. In: Proceedings of Recent Advances in Interdisciplinary Trends in Engineering & Applications (RAITEA), Indore, India, 2019.
22. OSWOS. Reluctance motor types overview and detailed function. [Online]. 2024. OSWOS. Available at https://oswos.com/reluctance-motor/
23. Xue XD, Cheng KWE, Cheung NC. Selection of electric motor drives for electric vehicles. In: 2008 Australasian Universities Power Engineering Conference, Sydney, New South Wales, Australia, December 14–17, 2008. pp. 1–6.
24. Karki A, Phuyal S, Tuladhar D, Basnet S, Shrestha BP. Status of pure electric vehicle power train technology and future prospects. Appl Syst Innov. 2020; 3 (3): 35.
25. Kumar MS, Revankar ST. Development scheme and key technology of an electric vehicle: an overview. Renew Sustain Energy Rev. 2017; (70): 1266–1285.
26. Lu K, Ritchie E. Preliminary comparison study of drive motor for electric vehicle application. In: Fifth International Conference on Electrical Machines and Systems, ICEMS, Shenyang, China, August 18–20, 2001. Vol 2, pp. 995–998.
27. Sale A. An overview of the market for electric vehicles. In: IEE Colloquium on Motors and Drives for Battery Powered Propulsion, London, UK,. April 15, 1993. pp. 2/1–2/7.
28. Rahman KM, Ehsani M. Performance analysis of electric motor drives for electric and hybrid electric vehicle applications. In: Power Electronics in Transportation, Dearborn, MI, USA, October 24–25, 1996. pp. 49–56.
29. Henneberger G. Brushless motors for electric and hybrid vehicles. IEE Colloquium on Machines and Drives for Electric and Hybrid Vehicles (Digest No: 1996/152), London, UK, June 28, 1996. pp. 2/1–2/4.
30. Vaez S, John VI. Minimum loss operation of PM motor drives. In: 1995 Canadian Conference on Electrical and Computer Engineering, Montreal, Quebec, Canada, September 5–8, 1995. Vol. 1, pp. 284–287.
31. Patterson DJ. High efficiency permanent magnet drive systems for electric vehicles. In: 23rd International Conference on Industrial Electronics, Control, and Instrumentation, New Orleans, LA, USA, November 14, 1997. Vol. 2, pp. 937–942.
32. Friedrich G, Kant M. Choice of drives for electric vehicles: a comparison between two permanent magnet AC machines. IEE Proc Electric Power Appl. 1998; 145 (3): 247–252.
33. Chan CC, Chau KT. An advanced permanent magnet motor drive system for battery-powered electric vehicles, IEEE Trans. Vehic Technol. 1996; 45 (1): 180–188.