*Journal of Scientific Research & Reports*

*24(6): 1-6, 2019; Article no.JSRR.50678*
*ISSN: 2320-0227*

# Review of Motors for Electric Vehicles

**Tahir Aja Zarma[1], Ahmadu Adamu Galadima[1] and Maruf A. Aminu[1*]**

[1]*Department of Electrical and Electronics Engineering, Nile University of Nigeria, Abuja, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. Author TAZ conducted literature search and prepared study introduction. Author AAG prepared study details and conclusion. Author MAA prepared the abstract and reorganized the manuscript. All authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/JSRR/2019/v24i630170
Editor(s):
(1) Suleyman Korkut, Duzce University, Turkey.
Reviewers:
(1) Vikas Sharma, India.
(2) Yuanbin Yu, Jilin University, China.
(3) Ali Algaddafi, University of Bradford, UK.
Complete Peer review History: https://sdiarticle4.com/review-history/50678

***Review Article***

***Received 11 June 2019***
***Accepted 19 August 2019***
***Published 04 October 2019***

## ABSTRACT

The need for clean energy and removal of toxic emission from internal combustion engines have led researchers and engineers into exploring and developing new drive systems. The development of hybrid cars has greatly reduced the emission level of vehicles. However, this is not enough. The purely electrical vehicles are 100% clean in service and as such their deployment is of great importance. Therefore, these vehicles replace the internal combustion engine in conventional cars and automobiles with electric motors. Hence, the need for the motor drive in an electric vehicle that is highly efficient with low weight, high power density and cheaply available in the market. In this paper, a review of different electric motors with respect to their design simplicity, cost, ruggedness and efficiency is presented. Finally, the brushless DC motor is proven to be an efficient and most suitable candidate for propulsion drive in electric vehicles and hybrid electric vehicles. However, its control is insufficient. A conceptual method to improve its control is also presented.

*Keywords: Electric motors; EVs; internal combustion engines; ICEs.*

## 1. INTRODUCTION

Following a growing outcry from environmental activist and government policies, it has become imperative that gas emission needs to be cut significantly because of its effect on the ozone layer [1]. Conventional mobility systems (vehicles) are driven by Internal Combustion

**Corresponding author: E-mail: maruf.aminu@gmail.com;*

Engines (ICE) and thus they burn gas, petrol into oxides of hydrocarbons thereby affecting the environment. While research has been directed towards clean energies, it has given rise to the advancement and the evolution of Hybrid Electric Vehicles (HEVs) which use both ICE and electric motors to propel their wheels [2-4]. Furthermore, purely Electric Vehicles (EVs) have since been in the market and running [5]. These vehicles use one or more electric motors for their propulsion [6]. Researchers are now exploring use of renewable energy including solar, wind and tidal waves for sustainable mobility [7-10].

An electric vehicle consists of three major subsystems; the energy source subsystem, the auxiliary subsystem and the electronic propulsion subsystem [3,11,12]. The electronic propulsion subsystem comprises an electronic controller, the power converter, the mechanical transmission and the electric motor. In this work, a review of different motors available as propulsion for electric vehicle is presented (Fig. 1).

The development of electrical drives dates back to the 18$^{th}$ century when Faraday demonstrated the principle of electromagnetic induction [14]. Following a proposal of Faraday's law, electric motors were invented and that bred the two major classes of motors: Alternating Current and Direct Current motors.

Typically, an electric motor consists of a rotor, stator, windings, air gap and commutators/ converters. Depending on a different arrangement of these components different types of electric motors are constructed [15]. Those electric motors that do not require brushes for commutation or energy conversion are called brushless permanent magnet motors [16]. Furthermore, motors can be categorized according to the shape of their back-Electromotive-Force (Back-EMF). Their shape can either be sinusoidal or trapezoidal. Based on their construction and energy interchange principles, they can be Permanent Magnet AC Synchronous Motors (PMSM) or Brushless DC motors (BLDC) [17].

For an electric motor to be successfully deployed as the drive for EVs, it should be highly efficient, it should have great power density and should be cost-effective [11]. Furthermore, motor drives in EVs, unlike industrial motors and conveyors, require; frequent start/stops, high rates of acceleration/deceleration, high torque at low speed, low torque at high-speed and wide speed ranges. However, the specification of the motor depends on its application. This application includes systems for home usage, regular vehicle and heavy-duty vehicles. Furthermore, the performance of motors depends mainly on vehicle duty cycle, thermal characteristics and the cooling mechanism implemented [11]. The classification of various motors used in traction is shown in Figure 2. A brief literature review on the motors used for traction in EV/HEVs is presented below. In this work, a literature review of both AC and DC motors is presented on the basis of the features mentioned earlier.

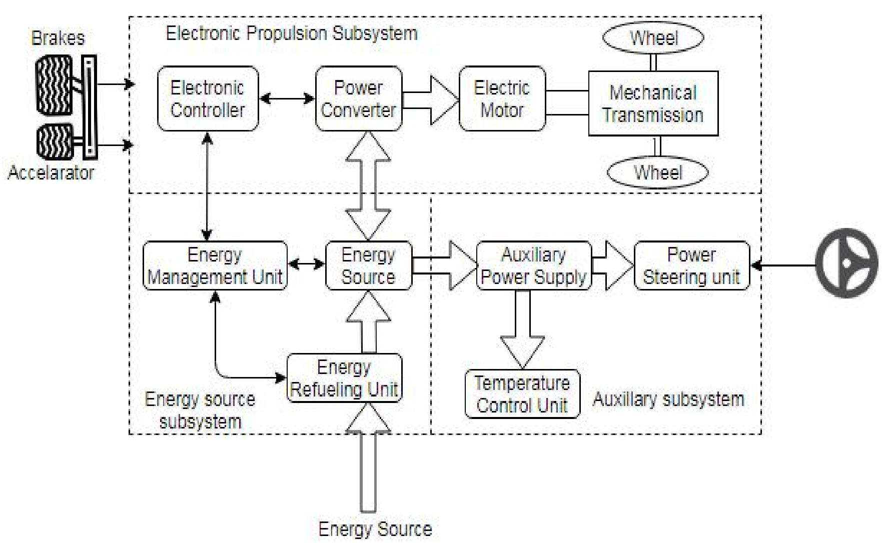


**Fig. 1. Block diagram of an electric vehicle [13]**

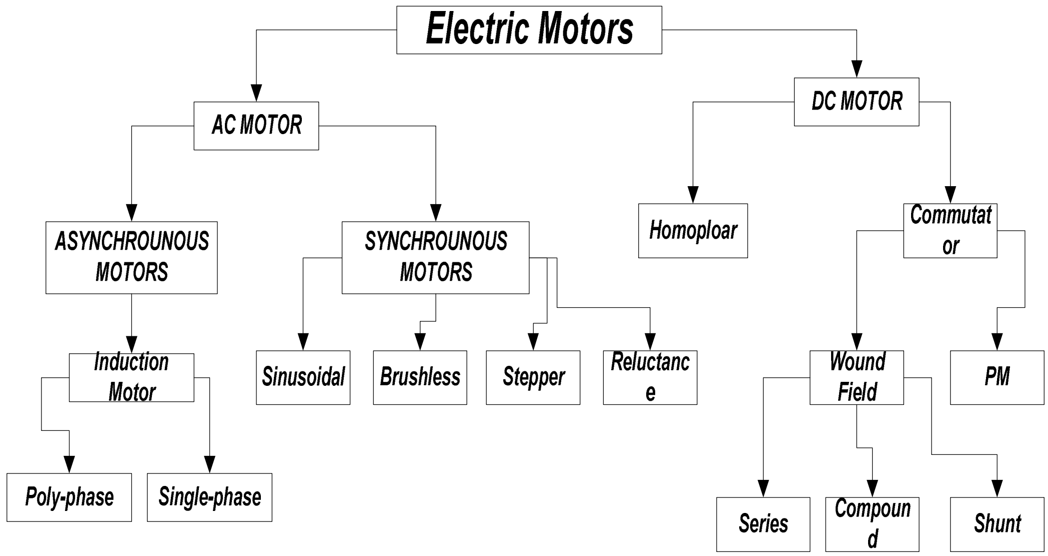


**Fig. 2. Classes of electric motors**

The rest of the paper is organized as follows; Section 2 discusses and presents different AC motors available stating their strength, weakness, uses and concept of control methods. Furthermore, their power density, efficiency and cost are also presented. A conceptual extended Kalman filter method of estimating the rotor position in a brushless permanent magnet motor which is still under development is suggested and presented in Section 3 with concluding remarks in Section 4.

## 2. THE ALTERNATING CURRENT MOTORS

This section reviews sinusoidally-powered electric motors. These are further divided into synchronous and asynchronous motors.

**Synchronous Motors:** Synchronous motors are motors where the shaft of the rotor is synchronized with the frequency of the supply current. In these motors, the period of the rotor is exactly the same as that of the supply. Available synchronous motors include permanent magnet synchronous motor, stepper motor and switched reluctance motor.

### 2.1 Permanent Magnet Synchronous Motor (PMSM)

This motor shares some similarities with the BLDC motor, but is driven by a sinusoidal signal to achieve lower torque ripple [18]. The sinusoidal distribution of the multi-phase stator windings generates a sinusoidal flux density in the air gap that is different from BLDC motor's trapezoidal flux density. This motor possesses the feature of an induction motor and a brushless dc motor. The motor has a permanent magnet rotor and winding on its stator. Furthermore, the stator of this motor is designed to produce sinusoidal flux which resembles that of an induction motor. The power density of this motor is higher than induction motors with the same ratings since there is no stator power dedicated to magnetic field production. Today, these motors are designed to be more powerful while also having a lower mass and lower moment of inertia. This motor can generate torque at zero speed, highly efficient and produces high power density compared to an induction motor. However, this motor requires a drive to operate. To achieve the specifications of high torque at low speed, high density and high efficiency, this motor uses Variable Frequency Drive (VFD). However, the VFD control technique increases the complexity of the system and hence requires careful attention to precisely control its speed. Hence the cost of this motor is on the higher side as compared to the induction motor [19]. Furthermore, these motors are characterized by design simplicity but with relatively low output power. Similar to induction motors, these PMSM utilizes VFD for high-performance applications. Because of their inherently high power density and high efficiency, they have been accepted as having great potential to compete with induction motors for EV and HEV applications.

### 2.2 The Stepper Motor

The stepper motor and switched reluctance motor have the same structure. The stator of a stepper motor consists of concentrated winding coils, while the rotor is made of soft iron laminates without coils [20]. Torque is produced in these motors when current switches from one set of stator coils to another set of coils. The switching currents from stator windings generate magnetic attraction between rotor and stator to rotate the rotor to the next stable position, or "step" [21]. The rotational speed is determined by the frequency of the current pulse, and the rotational distance is determined by the number of pulses. Since each step results in a small displacement, a stepper motor is typically limited to low-speed position-control applications [22]. The ability to move a specific step makes these devices commonly used in positioning mechanisms. Stepper motors are characterized by their moving and holding torque which, if exceeded, the motor slips and hence the motor loses count. This motor produces torque through magnetic reluctance, magnetic attraction or both. The motor doesn’t offer dynamic speed control. The motor can only be accelerated at full toque to full speed and decelerates at full torque. Hence, the motor offers greater torque for a given speed. Therefore, this motor is ideal for precision and position control purposes, making it unsuitable for EV application [23].

### 2.3 The Switched Reluctance Motor

The rotor in the Switched Reluctance (SR) motor cannot generate a magnetic field around itself because of the absence of coils in the rotor, therefore, no reactive torque is produced in an SR motor. Torque in these motors is produced when a stator phase is energized, the stator pole pair attracts the closest rotor pole pair toward alignment of the poles [24]. This way, high-torque ripple is generated which contributes to acoustic noise and vibration. However, due to its simple design, SR motor is very economical to build and is perhaps the most robust motor available [21]. This motor relatively produces lower torque compared with the stepper motor. Hence, its use is not popular in EV application.

#### 2.4 Asynchronous Motor (Induction Motor)

In this motor, the current in rotor winding is obtained from the field of the stator winding by electromagnetic induction. The rotor current is now utilized for torque production. The popular asynchronous motor available is the *induction motor*. In this motor, a sinusoidal AC current is used to excite the stator to create a rotating magnetic field that induces a current in the rotor; the induced current in the rotor generates a relative magnetic field in the rotor [25]. The magnetic fields in the rotor and the stator run at slightly different frequencies and hence generate torque [26]. The induction motors are characterized with a cheaper cost, absence of brushes, commutators and low maintenance. These features make the induction motor attractive in EVs. However, the need for converting the power supply from DC to AC demands more circuitry and hence complex control schemes [27].

## 3. DIRECT CURRENT MOTORS

In this section, the different DC motors available are presented. Motors such as brushed DC and brushless DC are presented in terms of their respective power density, efficiency and cost.

### 3.1 Brushed DC motor

A brushed DC motor consists of a commutator and brushes that convert a DC current in an armature coil to an AC current. As current flows through the armature windings, the electromagnetic field repels the nearby magnets with the same polarity and causes the winging to turn to the attracting magnets of opposite polarity. As the armature turns, the commutator reverses the current in the armature coil to repel the nearby magnets, thus causing the motor to continuously turn. This motor can be driven by DC power; hence it is very attractive for low-cost applications. However, some drawbacks of brushed DC motor are the arcing produced by the armature coils on the brush-commutator surface generating heat, wear, and electro-magnetic interference (EMI) [28]. These characteristics of the brushed motor indicate that it is more suitable in applications where high efficiency is not a major concern. This renders the use of this type of motor less attractive in EV applications.

### 3.2 Brushless DC motor

The brushless DC (BLDC) motors are the most popular and widely used in control applications [29] and are configured into single-phase, 2-phase and 3-phase [30]. The simple structure, ruggedness, and low-cost of a BLDC motor make it a viable candidate for various general-purpose applications. The BLDC combined with a suitably controlled converter provides several desired characteristics for an efficient drive system. One major advantage of BLDC is its enhanced speed versus torque characteristics as compared with other electric motors [31]. Furthermore, the BLDC accomplishes commutation electronically using rotor position feedback to determine when to switch the current [32]. This motor is built with a permanent magnet rotor and wire-wound stator poles. The rotor is formed from the permanent magnet and can alter from two-pole to eight-pole pairs with alternate North (N) and South (S) poles [33]. The stator windings work with the permanent magnets on the rotor to generate a uniform flux density in the air gap [34]. This permits the stator coils to be driven by a constant DC voltage (hence the name brushless DC). The rotor position of a BLDC sensed using *hall effect* sensors is very important, this gives the information about winding that is energized at an instant and the winding that will be energized in sequence [35]. Whenever the rotor magnetic poles pass near the *hall effect* sensors, they give a high or low signal, suggesting the N or S pole is passing near the sensors. The exact order of commutation can be estimated, depending upon the combination of signals from these three *hall effect* sensors.

Furthermore, sensorless control strategies can be used to eliminate the position sensors, thus reducing the cost and size of the motor. In fact, control methods, such as back-EMF (BEMF) and current sensing can provide enough information to estimate with sufficient precision the rotor position and, therefore, to operate the motor with synchronous phase currents. Perhaps, the most popular BEMF methods rely on one technique called the *Zero-Crossing Point* (ZCP), being the only point to provide the rotor position information at either 0° or 180° electrical. The ZCP method is succeeded by a phase shift of 30° or 90° to match the commutation instances. Any detection error of the ZCP results in a sub-optimal phase current [36].

The BLDC motor offers excellent power density as compared with other motors, higher torque, reduced operational and mechanical noise, and elimination of electromagnetic interference and offers excellent efficiency. Hence, this motor is the most popular in EV application [11].

## 4. CONCLUSION

In this work, a review of different motors used as electric drive trains is presented. Working principles, operational requirements, excellent features and drawbacks of all motors available are discussed in detail and presented. The brushless DC motor has proven to be an efficient candidate for application in electric drive trains. This motor offers extraordinary power density, high efficiency and is cheaply available. The popularity of this motor as used as an electric drive train is also presented.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Omer AM. Energy, environment and sustainable development. Renewable and Sustainable Energy Reviews. 2008;12: 2265-2300.
2. Xue X, Cheng K, Cheung N. Selection of electric motor drives for electric vehicles. In 2008 Australasian Universities Power Engineering Conference. 2008;1-6.
3. Maggetto G, Van Mierlo J. Electric and electric hybrid vehicle technology: A survey; 2000.
4. Severinsky AJ. Hybrid electric vehicle. ed: Google Patents; 1994.
5. Chan CC. The state of the art of electric, hybrid, and fuel cell vehicles. Proceedings of the IEEE. 2007;95:704-718.
6. Propfe B, Kreyenberg D, Wind J, Schmid S. Market penetration analysis of electric vehicles in the German passenger car market towards 2030. International Journal of Hydrogen Energy. 2013;38:5201-5208.
7. Patterson DJ, Henein NA. Emissions from combustion engines and their control; 1981.
8. Lefebvre AH, Ballal DR. Gas turbine combustion: Alternative fuels and emissions: CRC Press; 2010.
9. Murugesan A, Umarani C, Subramanian R, Nedunchezhian N. Bio-diesel as an alternative fuel for diesel engines: A review. Renewable and Sustainable Energy Reviews. 2009;13:653-662.
10. Eberle U, Von Helmolt R. Sustainable transportation based on electric vehicle concepts: A brief overview. Energy & Environmental Science. 2010;3:689-699.
11. Singh KV, Bansal HO, Singh D. A comprehensive review on hybrid electric vehicles: Architectures and components. Journal of Modern Transportation. 2019;1-31.

12. Chan C, Wong Y. The state of the art of electric vehicles technology. In The 4th International Power Electronics and Motion Control Conference. IPEMC. 2004;46-57.
13. Chan C, Chau K. Modern electric vehicle technology. Oxford University Press on Demand. 2001;47.
14. Laramore RD. An introduction to electrical machines and transformers: Wiley; 1990.
15. Gieras JF. Permanent magnet motor technology: Design and applications: CRC Press; 2002.
16. Bonfe M, Bergo M. A brushless motor drive with sensorless control for commercial vehicle hydraulic pumps. In 2008 IEEE International Symposium on Industrial Electronics. 2008;612-617.
17. Bianchi N, Bolognani S, Jang JH, Sul SK. Comparison of PM motor structures and sensorless control techniques for zero-speed rotor position detection. IEEE Transactions on Power Electronics. 2007; 22:2466-2475.
18. Mattavelli P, Tubiana L, Zigliotto M. Torque-ripple reduction in PM synchronous motor drives using repetitive current control. Power Electronics, IEEE Transactions. 2005;20:1423-1431.
19. Novotny DW, Lipo TA. Vector control and dynamics of AC drives. Oxford University Press. 1996;1.
20. Hendershot JR. Polyphase switched reluctance motor. ed: Google Patents; 1992.
21. Reid BA, Deline JR. Closed-loop control system for a stepping motor. ed: Google Patents; 1987.
22. Bodson M, Chiasson JN, Novotnak RT, Rekowski RB. High-performance nonlinear feedback control of a permanent magnet stepper motor. Control Systems Technology, IEEE Transactions. 1993;1:5-14.
23. Athani V. Stepper motors: Fundamentals, applications and design: New Age International; 1997.
24. Ab Ghani MR, Farah N, Tamjis M. Field oriented control of 6/4 SRM for torque ripple minimiaztion.
25. Levi E, Bojoi R, Profumo F, Toliyat H, Williamson S. Multiphase induction motor drives-A technology status review. Electric Power Applications. 2007;1:489-516.
26. Trzynadlowski AM. Control of induction motors: Academic Press; 2000.
27. Zeraoulia M, Benbouzid MEH, Diallo D. Electric motor drive selection issues for HEV propulsion systems: A comparative study. IEEE Transactions on Vehicular technology. 2006;55:1756-1764.
28. Patel TK. Motion-control system of bench-top ct scanner. Wright State University; 2008.
29. Yedamale P. Brushless DC (BLDC) motor fundamentals. Microchip Technology Inc. 2003;20:3-15.
30. Oney WR. High power density brushless dc motor. ed: Google Patents; 1980.
31. Sen PC. Electric motor drives and control-past, present, and future. Industrial Electronics, IEEE Transactions. 1990;37: 562-575.
32. MacMinn SR, Roemer PB. Rotor position estimator for switched reluctance motor. ed: Google Patents; 1988.
33. Kusase S, Umeda A, Hukaya S, Inomata N, Irie H, Ishida H. Rotor for a rotating electric machine. ed: Google Patents; 1998.
34. Jahns TM, Kliman GB, Neumann TW. Interior permanent-magnet synchronous motors for adjustable-speed drives. Industry Applications, IEEE Transactions on. 1986;738-747.
35. Toliyat HA, Kliman GB. Handbook of electric motors vol. 120: CRC Press; 2004.
36. Gamazo-Real JC, Vázquez-Sánchez E, Gómez-Gil J. Position and speed control of brushless DC motors using sensorless techniques and application trends. Sensors. 2010;10:6901-6947.




*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*https://sdiarticle4.com/review-history/50678*