COMPARISON OF ELECTRIC MOTORS FOR ELECTRIC VEHICLE APPLICATION

Swaraj Ravindra Jape[1], Archana Thosar[2]

[1]B.E, Electrical Engineering Department, Government College of Engineering, Aurangabad, Maharashtra, India
[2]Professor, Electrical Engineering Department, Government College of Engineering, Aurangabad, Maharashtra, India

Abstract

Electric vehicles with higher energy efficiency, low maintenance cost and pollution free operation, are offering great alternative to popular conventional IC engine vehicles. Also, with the advancement in technology, electric vehicle manufacturers are able to overcome the traditional drawbacks of electric vehicles, making it more and more suitable for modern day transportation. A motor in an electric vehicle provides the necessary force for the propulsion of a vehicle, which makes it the heart of electric vehicles. Different types of electric motors are compared on the basis of certain parameters which should be considered for selecting a particular motor type for electric vehicle application. Comparison is tabulated for some parameters. Also, characteristic graphs of different motors are included at some points.

Keywords: *Electric vehicle, DC brushed motor, BLDC motor, Induction motor, Synchronous motor, Switched reluctance motor.*

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1. INTRODUCTION

In EV's, electric energy is the main source of power for propulsion of a vehicle. In electric vehicles, electrical energy is converted into mechanical (rotational) energy by electric motors. This rotational energy is applied to wheels of a vehicle through an appropriate transmission system which in turn causes propulsion. A vehicle with four motors can be considered as the most efficient model in electric vehicles [1]. Electric vehicles can use electric energy as a sole source of power or can use batteries in conjunction with gasoline engines to power the vehicle. Battery, electric motor and controller are the core components of any electric vehicle. Electric vehicle can be broadly represented as shown in Figure 1.

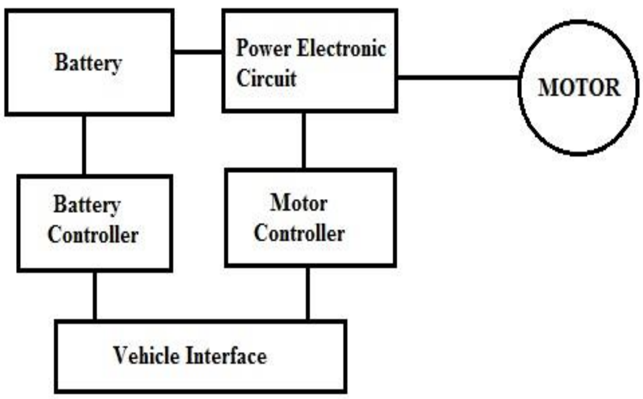

Fig-1: Basic components of an electric vehicle

Electric motors are also specially designed for their specific use in electric vehicles. Electric vehicles may incorporate AC or DC motors as per design engineer's choice or depending on the intended use of electric vehicle. Over the years there has been a significant research in the field of electric motors and different types of AC and DC motors have been developed. This gives electric vehicle manufacturers a wide range of different electric motors to choose from as per their requirement. Selection of a particular type of motor for an electric vehicle must be done judiciously as motor characteristics affect the overall performance of a vehicle.

2. MOTORS COMMONLY USED IN EV's

Different types of motor exhibit different characteristics, which makes it important to evaluate motors on some basic parameters for choosing a particular type of motor for an electric vehicle. Electric motors used in electric vehicle should have important attributes like simple design, high specific power, low maintenance cost, and good control. Motors that are widely used by electric vehicle manufacturers are DC brushed motors, DC brushless motors, Induction (Asynchronous) motor, Synchronous motor, Switched Reluctance motor.

2.1 DC Brushed Motor

In DC brushed motor, brushes along with commutators provide a nexus between external supply circuit and armature of the motor. Brushes can be made up of carbon, copper, carbon graphite, metal graphite and are mostly rectangular in shape [2]. Wearing of commutators due to continuous cutting with brushes is one of the main drawbacks of DC brushed motors. Also, friction between brushes and commutators, limits the maximum motor speed.

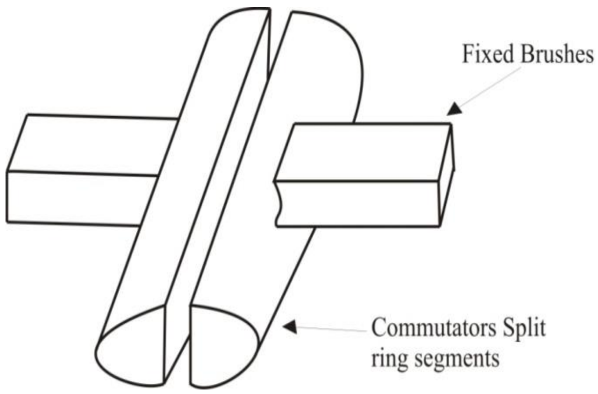

Fig-2: Brush and Commutators arrangement

DC brushed motors have the ability to achieve high torque at low speeds, which makes them suitable for traction system [3]. Figure 2 shows simple brush and commutators arrangement in DC brushed motors. Depending upon power output and voltage rating, DC brushed motors can have two, four or six poles and the field winding may be series or shunt connected. Poor power density as compared to PMSM or BLDC motor is another drawback of brushed DC motor for use in electric vehicles.

2.2 DC Brushless Motor

DC brushless motor provides certain advantages over DC brushed motor, like less maintenance and higher efficiency. Mechanical commutation as in brushed DC motor is replaced by equivalent electronic commutation (inverter circuit and rotor-position sensing element) circuit in DC brushless motor [3], [4].

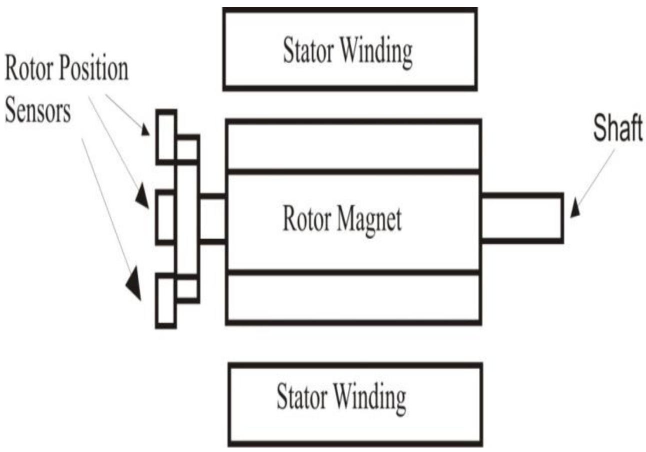

Fig-3: Basic arrangement of rotor and sensor elements in BLDC motor

According to National Electrical Manufacturers Association (NEMA), BLDC motor is defined as rotating self-synchronous machine with a permanent magnet rotor and known rotor shaft positions for electronic commutation [5]. Figure 3 shows basic arrangement of stator, rotor and position sensors in BLDC motor. BLDC motor provides higher torque at the peak values of current and voltage as compared to other motors [4]. Due to better operating characteristics at higher speeds, these motors find their application in compressors, pump and ventilation system.

2.3 Induction (Asynchronous) Motor

Three phase induction motors are widely used in electric vehicles because of high efficiency, good speed regulation and absence of commutators. 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 [3]. As speed of rotor is different (less) than speed of revolving field (synchronous speed), these motors are also called as asynchronous motor.

2.4 Synchronous Motor

In synchronous motors, rotor rotates at synchronous speed. The rotor is excited from a DC supply, while stator is connected to a three phase AC supply. Therefore, polarities of stator poles are continuously changing while rotor pole polarities are constant.

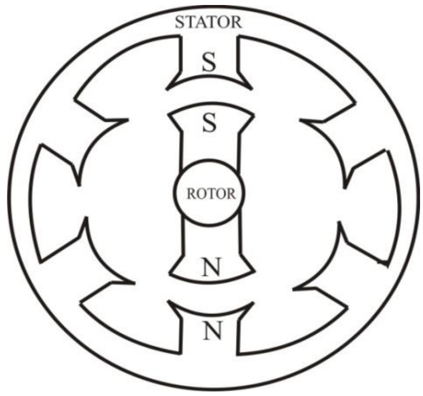

Fig: 4 (a) Rotor sand stator poles having same polarity

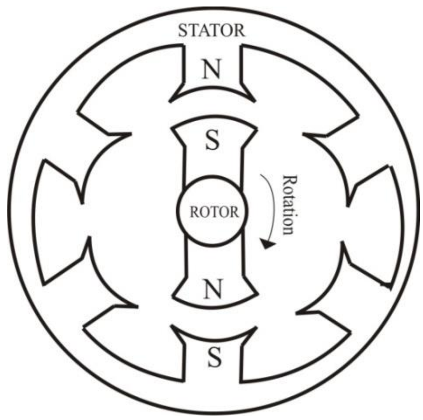

Fig: 4 (b) Rotor and stator poles having opposite polarity and rotor is rotated by external means

Consider that initially stator and rotor are having polarities as shown in Figure 4(a). At this instant rotor S-pole is repelled by stator S-pole. Now, during another half-cycle, stator poles will change their polarities and now rotor S-pole will be attracted towards stator N-pole. Thus, rotor will experience pulsating torque and due to rotor inertia, it will not rotate in either direction. Therefore, synchronous motor does not have self-starting toque. Now, if the rotor is rotated by external means such that rotor poles are continuously under the influence of stator poles of opposite polarity even with continuously changing polarity, rotor will start rotating in one direction. Figure 4(b) shows rotor S-pole and stator N-pole interlocked with each other and rotor rotating in clockwise direction. Now, even if external means are removed, rotor and stator poles are interlocked, and rotor will rotate with synchronous speed. Rotor should be rotated with such speed that it moves through a distance of pole pitch within half time period of supply. Due to its high efficiency and high torque density, synchronous motor finds its application in servo, wind turbine and electric vehicles [6].

2.5 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 [7].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 [8].

3. PARAMETERS

3.1 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.

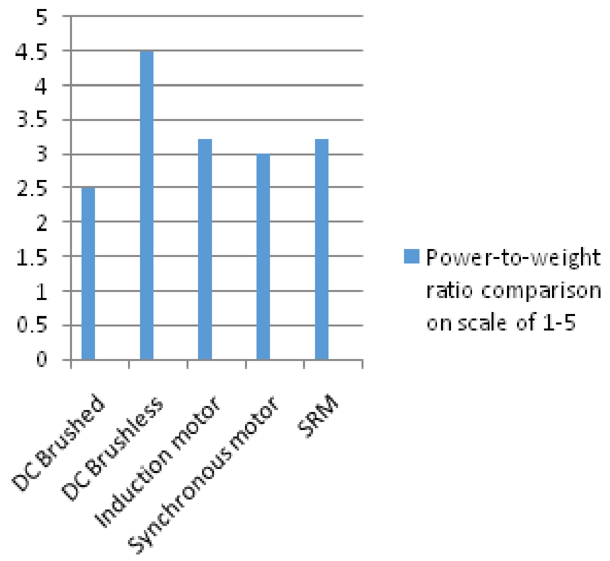

Chart -1: Power-to-weight ratio comparison of different electric motors

3.2 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. The ideal mechanical characteristics of an electric motor for electric vehicle application are as shown in Figure 5 [9].

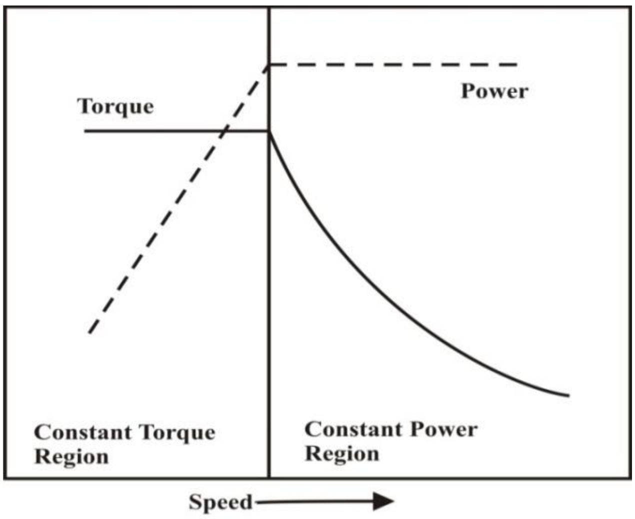

Fig-5: Ideal mechanical characteristics of electric motor in EV

When electric vehicle is used where frequent staring/stopping is required, motor is operated in constant torque region, while at high speed; it is operated in constant power region. As shown in Figure-6 (a), DC series wound motor has high starting torque. Also, speed decreases with increase in torque. DC shunt motors have medium staring torque, but speed decreases slightly with increase in torque as shown in Figure 6 (b). Therefore DC shunt wound motors are used in constant speed application.

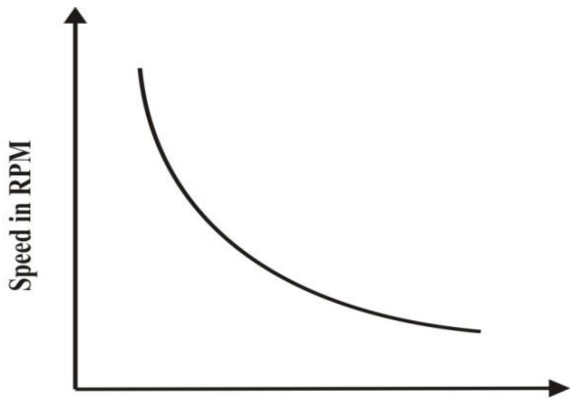

Fig-6: (a) Torque versus speed characteristics of DC Series Wound Motor

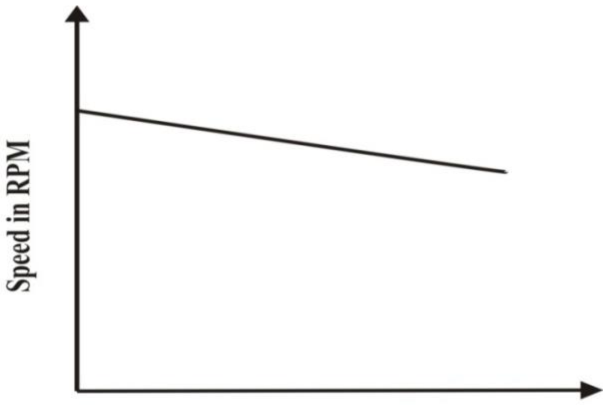

Fig-6: (b) Torque versus speed characteristics of DC Shunt Wound Motor

Torque-speed characteristics of brushless DC motor is more drooping than that of DC shunt motor [2].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 [3]. Torque-speed characteristic for medium value of rotor resistance is as shown in Figure 7.

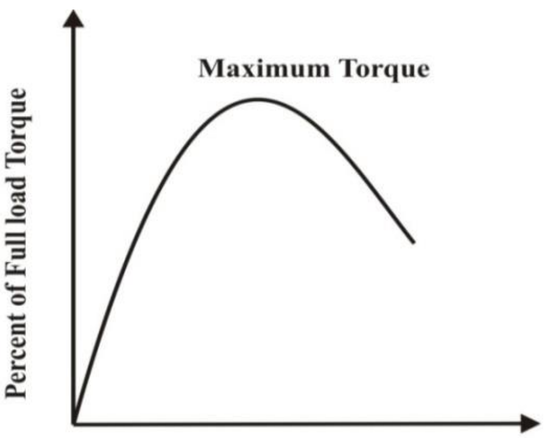

Fig-7: Torque slip characteristics of three phase Induction Motor

Synchronous motor operates at synchronous speed only and this speed of motor is independent of variation in load. Therefore synchronous motors are used in vehicle where constant speed is required. The speed at which back emf is equal to bus voltage is called as base speed. 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 [10],[11]. Torque-speed characteristic of Switched Reluctance Motor is as shown in Figure 8.

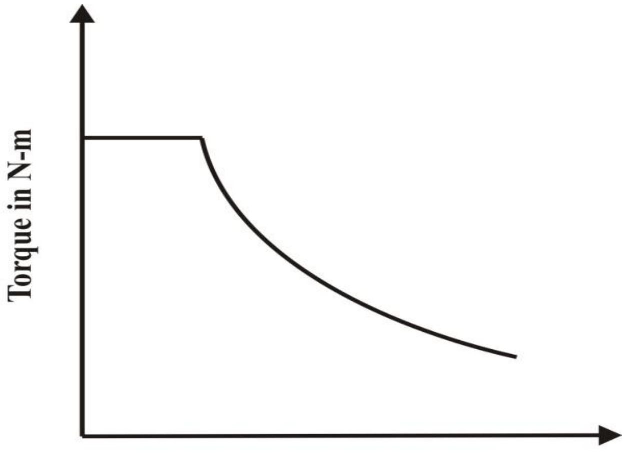

Fig-8: Torque versus speed characteristics of Switched Reluctance Motor

3.3 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 [12]. 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 [13].

Table-1: Efficiency Comparison of Different Electric Motors

Motor Type	Peak Efficiency (Percent)	Efficiency at 10% load (Percent)
DC Brushed Motor	85-90	80-85
DC Brushless Motor	>95	70-80
AC Induction Motor	>90	>90

Synchronous Motor	>92	80-85
Switched Reluctance Motor	<95	>90

3.4 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.

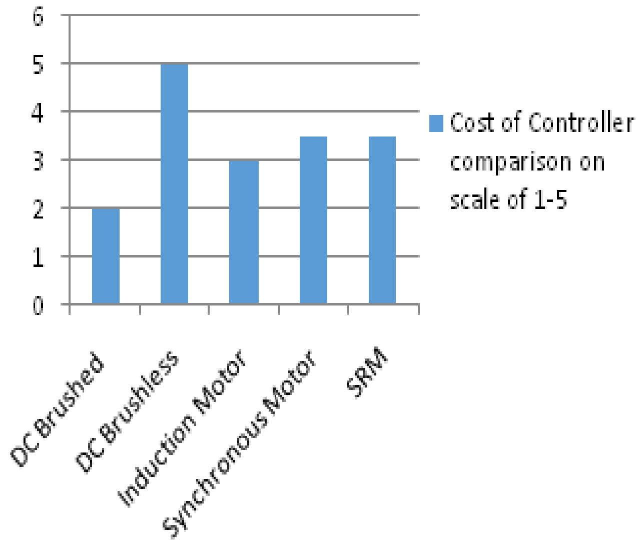

Chart -2: Cost of Controller Comparison for Different Electric Motor

3.5 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.

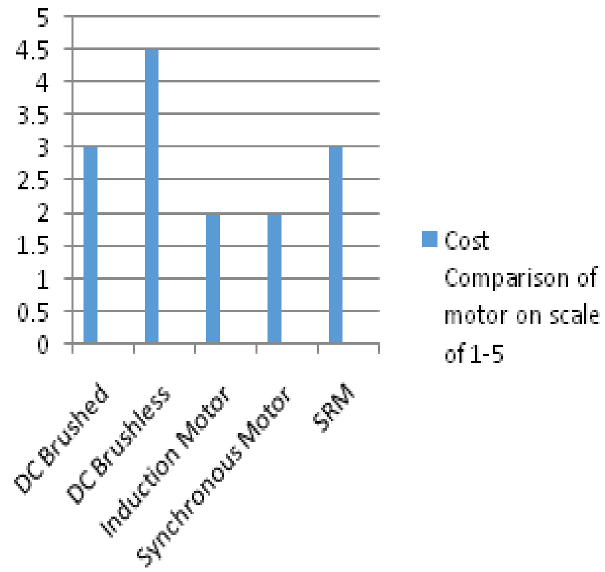

Chart -3: Cost of motor Comparison for Different Electric Motor

4. CONCLUSION

In this study, we compare five 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 the following.

1. DC brushed motor are easy to control, provide high torque at lower speeds but have high maintenance cost, large size, low efficiency.
2. BLDC motor has higher power-to-weight ratio, but its maintenance cost, cost of controller is high.
3. 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.
4. Synchronous motor has higher efficiency at lower speeds and improves battery utilization and driving range. Synchronous motor is preferred where constant torque is required.
5. 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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