# Analyzing the Characteristics of Different Types of Motors Used in Electric Vehicles

**A.Geetha, T.M. ThamizhThentral, SnehalArvindSilekar, GracyKatiyar, Gaurav Mishra, SharadBhowmick**

***Abstract--- This document deals with work done by the students on analyzing the characteristics of different types of motor used in an hybrid electric vehicle, and to find out the most efficient motor for the same. Characteristics such as losses, efficiency, cost etc. are taken into consideration and compared, calculated to find out the efficiency of different types of motors under different conditions. The performance of motors under two major conditions is taken into account. Two different types of motors are used for the purpose and a better one is found out. All this is done by using MATLAB software and simulation of the motors are carried out and their torque is calculated using respective formulas, as a result the efficiency calculation is also carried out using suitable formulae. Two main types of motors such as BLDC and PMSM are used for the purpose, they are simulated on different conditions i.e once on a highway and another on a city road, their efficiency is calculated is on the same basis.***

***Keywords--- Electric Motors, Efficiency Calculation, Comparison, Electric Vehicle.***

## I. INTRODUCTION

Selection of the electric motor for electric vehicle system is a crucial step in designing the overall system. Many criteria such as efficiency, reliability, cost etc. has been taken into consideration. The most common motors used in hybrid electric vehicles and pure electric vehicles are dc motors, induction motor, PMSM, SRM and BLDC motor. In this project, PMSM and Brushless DC motors have been chosen. EV applications and vehicles with same characteristics but various motors are simulated by matlab software in different driving cycles to see and compare them. Motors are the most crucial part of a vehicle and so it is highly important to select the best motor. Previous generation motors had a lot of disadvantages such as heavy load, reduced flexibility, and performance degradation, therefore, these types of vehicles were soon out and in replacement of these types of motors, new modern built motors were formed. Their unique structure satisfied the growing requirements and makes use of a better propulsion system. A typical block diagram representing the modern electric drive system is as shown below in figure 1.

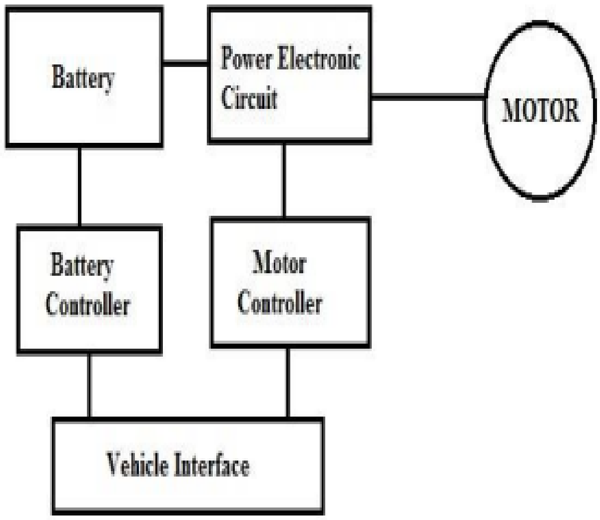


**Figure 1: Basic somponents of the elctric vehicle. [4]**

- The major components of any electric vehicle includes the battery, motor controller, electric engine, regenerative breaking, drive systems etc. It should always be considered that the vehicle is energy efficient and does little or no harm to the environment. In [3], a survey and comparison of characteristics of motor drives used in the EVs are presented. Regarding the proportion of research, the other three types including the induction, brushless DC and permanent magnet synchronous motors are greatly dominant.

## II. TYPES OF MOTORS USED

A lot of motors are used and available in the market. Three different types of motors are generally used in an electric vehicle.

Brush type motor is not at all used in an electric vehicle, as it is not suitable to be used in it. Permanent magnet motors are used by most of the manufactures in an electric vehicle except Tesla. Induction motor is used by Tesla and Toyota RAV-4 EV.

Tesla Model S has been used as a reference car for the different types of vehicle. A data sheet of the same model is illustrated in table1.

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**Geetha,** Assistant Professor, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, ChennaiTamilnadu, India.

**T.M. ThamizhThentral,** Assistant Professor, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Chennai, Tamilnadu, India.

**SnehalArvindSilekar,** UG Student, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Chenna, Tamilnadu, Indiai.

**GracyKatiyar,** UG Student, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Chennai,Tamilnadu, India.

**Gaurav Mishra,** UG Student, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Chennai, Tamilnadu, India.

**SharadBhowmick,** UG Student, Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Chennai, Tamilnadu, India.



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**Table 1: Specifications of Tesla S [6]**

| | | | |
|---|---|---|---|
| Length | 196.0" | Seating capacity | 5 adults |
| Wheelbase | 116.5" | Total cargo volume | 31.6 cu ft |
| Width | | Rear cargo volume | 26.3 cu ft |
| Track | 65.4" | With seats down | 58.1 cu ft |
| Front | 66.9" | Front trunk cargo volume | 5.3 cu ft |
| Rear | 4.6"-6.3" | Turning cirlce | 37 ft |
| Clearance | | Curb weight | 4,647.3 lbs |
| Head room | | Weight distribution | |
| Front | 38.8" | Front | 48% |
| Rear | 35.3" | Rear | 52% |

*A. Brushless type DC Motor*

Various types of motors are in common use. Among these, brushless DC motors feature high efficiency and excellent controllability, and are widely used in many applications. The BLDC motor has power saving advantages relative to other motor types. A 300V BLDC motor is used for the simulation and a similar rating PMSM is used for simulation and comparison. 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].

*B. Permanent Magnet Synchronous Motor*

A permanent-magnet synchronous motor (PMSM) uses permanent magnets embedded in the steel rotor to create a constant magnetic field. The stator carries windings connected to an AC supply to produce a rotating magnetic field. At synchronous speed the rotor poles lock to the rotating magnetic field. The major characteristics of PMSM are it is a close relative of the BLDC motor, its windings are on the stator, sinusoidal back emf waveforms on the winding, it is controlled with sinusoid.

*C. Speed and Time input for the motors*

Here, two outputs are taken for two different conditions. One is of the expressway or the highway and another case is of the city roads. A general graph is plotted for the same. Figure 2 represents the highway or the expressway and figure 4 represents the behaviour of the motor on a city road.

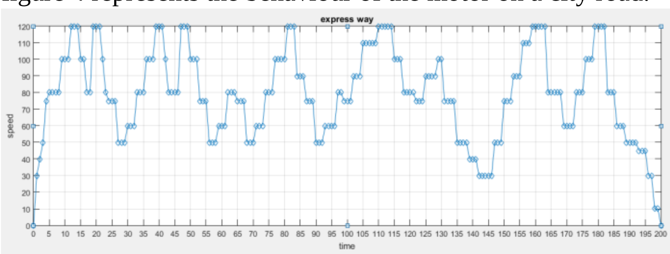


**Figure 2: Vehicle expressway driving cycle**

The variation of speed with time for a motor on an expressway is very different from that of the city roads. Speed is usually high and the variation is comparitively less, therefore, the characteristics of the motor will also differ from that of the city road which is illustrated in figure 3.

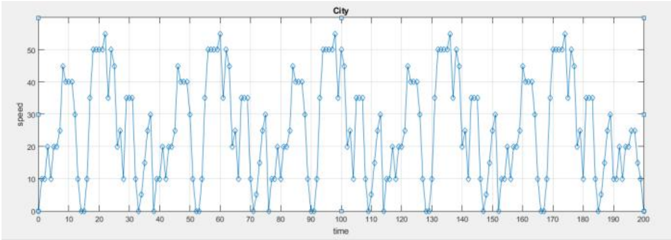


**Figure3: Vehicle city road driving cycle**

## III. SIMULATION

*A. Brushless DC motor*

A brudhless DC motor rated 200V was run for two different cases and the efficiency was calculated from the output graph of the simulation. The two cases were – the vehicle with BLDC motor on an expressway and a vehicle with BLDC motor on a city road. The duty cycle with both the cases is represented after the simulation is carried out. The motor specifications are given in figure 4.

3 HP Drive Specifications

| | | |
|---|---|---|
| Drive Input Voltage | | |
| | Amplitude | 220 V |
| | Frequency | 60 Hz |
| Motor Nominal Values | | |
| | Power | 3 hp |
| | Speed | 1650 rpm |
| | Voltage | 300 Vdc |

**Figure 4: Specifications of motor used in the simulation**

The simulation of this motor is performed on matlab for a total time period of **200seconds.**

*Case 1: when the vehicle is on an expressway*

The motor is connected to a battery and an inverter source instead of a direct voltage source. Considering that the motor is run on an expressway, the characteristics of the motor is found out by first implementing software simulation. For software simulation, a model of the motor is drawn out on matlab, and is run after proper implementation. The model is shown in figure 5.

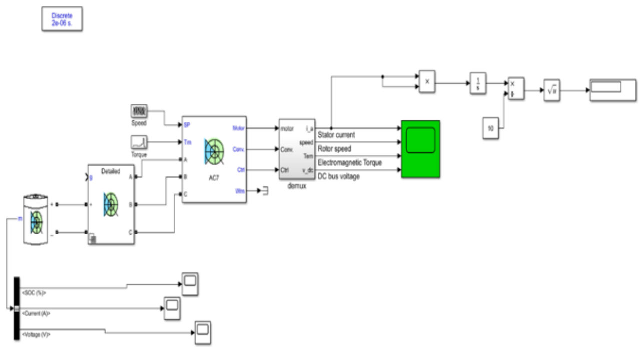


**Figure 5: Software model for BLDC motor**


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The software model of the motor consists of a voltage supply, BLDC motor drive, DE multiplexer, output display, speed torque calculator, integrator, pi gain calculator etc. the motor here is further made up of various components. The output of the motor when it is tested on an expressway is as shown in figure 6.

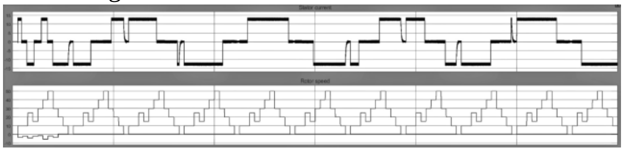

**Figure 6: Output of BLDC mtor on an expressway**

A vehcile on an expressway doesn't experience much deviation in speed on a expressway, therefore its characteristics is very different from that on a city road.

*Case 2: consider the motor on a city road*

A BLDC motor will have different characteristics when run on a city road, the major reason behind this is the increase in traffic, irregular speed etc. figure 7shows the output of a BLDC motor on a city road. The output is very different from the motor on an expressway and therefore the efficincy will also be different for the motor.

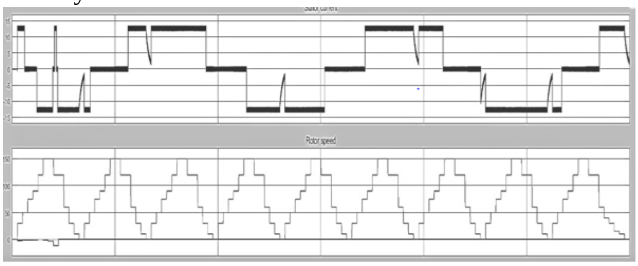

**Figure 7: BLDC mtor on a city road**

The total simulation is carried out for a time period of 200 seconds. The torque characteristics and the dc bus voltage characteristics are very similar for both the cases but the efficiency and losses are different which will calculated in the paper further.

*B. Permanent Magnet Synchronous Motor(PMSM)*

The permanent magnet synchronous motor or the PMSM motor uses permanent magnet embedded in a steel rotor to create a constant magnetic field. The stator carriers winding connected to an ac supply to produce a rotating magnetic field. At synchronous speed, the rotor poles lock to the rotating magnetic field. 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. These motors have several advantages: higher power density, higher efficiency and the more effective distribution of heat into the environment. However, these motors have intrinsically a narrow constant power region (Fig. 3-a). 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. Fig. 3-b shows the torque speed of a PMS motor with conduction angle control. Speed range can be extended to three of four times the base speed. A shortcoming of these motors is that they can be demagnetized due to the heat or armature reaction. [2] The PMSM is connected to a battery and an inverter source.

*Case 1: when the vehicle is on an expressway*

In this paper, we find the most efficient motor by comparing between BLDC and PMSM. For the same pupose, the simulation is carried out of the PMSM motor for a total time run time of 200 seconds. The duty cycle for the mentioned case is given in figure 8.

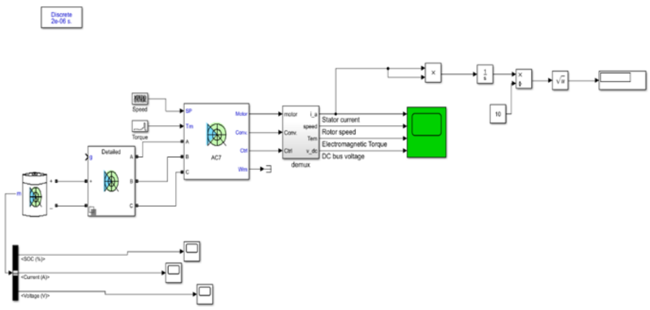


**Figure 8: Software model for PMSM motor**

The software model for PMSM includes the PMSM drive, voltage supply, mux, and blocks for calculation. A simulation is carried out for a time period of 200 seconds and the results are noted down.

The internal structure of the drive has been divided into three parts i.e the motor, the converter and the control. The simulation for a PMSM on an expressway is shown in figure 9.

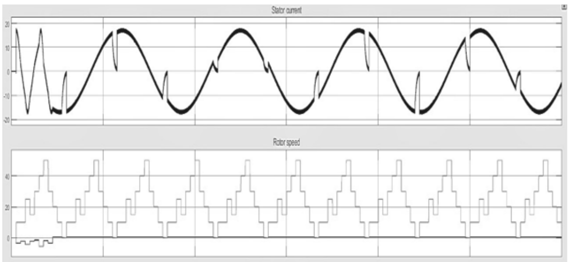

**Figure 9: PMSM motor on an expressway**

The duty cycle of the PMSM motor on an expressway is shown in the above figure and another simulation for the motor on a city road is carried out for better comparitive resulats.

*Case 2: when the vehicle is on a city road*

The characteristics of the vehicle on a city road is very different from that when it runs on an expressway. The irregular movement of other vehilces on the road, the speed, the velocity etc are factors taken into consideration. The simulation for the same is shown in figure 10.

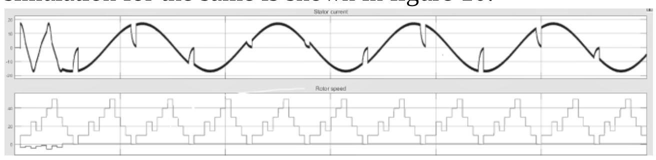

**Figure 10: Simulation of PMSM on a city road**

The simulation is very different from that carried on an expressway. The factors affecting it has been discussed earlier. After the simulation of all the four cases, the calculation is done using suitable formulae and a result is generated showing the efficincy of the motor in all the four cases.


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## IV. CALCULATION

The efficiency calculation is done for the four cases i.e BLDC motor on an expressway and a city road and PMSM motor on an expressway and a city road. Results were obtained as follows. The efficiency and loses were calculated as given in the below formulae.

*BLDC expressway*

$$\text{Efficiency} = \frac{\text{output power}}{\text{output power} + \text{losses}} \times 100 \quad (1)$$

Using (1), the efficiency for BLDC motor is calcualted which is summarised as follows.

For BLDC Motor-

1. On a Highway –
   Losses = 993.61 watts
   Output Power = 6155
   Efficiency = 86.1%
2. On a city road –
   Losses – 584.13 watts
   Output Power = 3445
   Efficiency = 85.5%

For PMSM Motor –

1. On a Highway –
   Losses = 1242.8 watts
   Output Power = 6155 watts
   Efficiency = 83.2%
2. On a city road –
   Losses = 839.82 watts
   Output Power = 3445
   Efficiency = 80.4%

The results are summarised in the given table 2. The table summarises the most efficient motor between BLDC and PMSM and gives the result that a BLDC motor is more efficient compared to the PMSM motor for a motor run on a highway or an expressway. For a city road, the efficiency of the BLDC motor is more compared to the PMSM motor, apart from the efficiency and losses calculation, other factors are also taken into consideration. The total factors are summarised in the conclusion. The force is calculated using (2).

$$F = f_r + f_w + f_g + f_a$$

$$= M_g f_r \cos(\alpha) + 0.5\rho A_f C_d V^2 \quad (2)$$

Where,

$F_r =$ rolling resistance of front and rear tyre

$F_w$ = Aerodynamic drag

$F_g =$ Grade climbing resistance

$F_d =$ Acceleration resistance

The given table shows the reference values for $C_d$ and $A_f$.

**Table 2**

| | $C_d$ | $A_f$ |
|---|---|---|
| Motor cycle with rider | 0.5-0.7 | 0.7-0.9 |
| Open convertible | 0.5-0.7 | 1.7-2 |
| Limousine | 0.22-0.4 | 1.7-2.3 |
| Coach | 0.4-0.8 | 6-10 |
| Truck without trailer | 0.45-0.8 | 6-10 |
| Truck with trailer | 0.55-1.0 | 6-10 |
| Articulated vehicle | 0.5-0.9 | 6-10 |

The following table 3 shows the value of the rolling friction for different types of vehicles.

**Table 3**

| | $f_r$ |
|---|---|
| Car tire on smooth tarmac road | 0.01 |
| Car tyre on concrete road | 0.011 |
| Car tyre on rolled gravel road | 0.02 |
| Tarmocadam road | 0.025 |
| Unpaved road | 0.05 |
| Bad earth tracks | 0.16 |
| Loose sand | 0.15 – 0.3 |
| Truck tyre on concrete road | 0.006 – 0.01 |
| Wheel on iron rail | 0.001 – 0.002 |

The result is calculated based on the given data, simulations and usual formulae to compute the efficiency of a motor based on its output power, losses and other factors. The result is summarised in the following table.

**Table 4**

| | BLDC Motor | | PMSM Motor | |
|---|---|---|---|---|
| | Highway | Cityroad | Highway | Cityroad |
| Efficiency | 86.1% | 85.5% | 83.2% | 80.4% |
| Losses | 993.6 | 584.2 | 1242.8 | 839.8 |
| $P_{out}$ | 6155 | 3445 | 6155 | 3445 |

## V. CONCLUSION

The simulation was carried out for two types of motor that is BLDC and PMSM to find the most effective motor out of them and the simulation, calculation was carried out to summarise the result. Apart from the regular calculations, other factors are also taken into consideration which is summarised in the given table. This shows that the BLDC motor is the most preferred motor for both the cases of the city road and the expressway when compared to a PMSM motor. BLDC has other advantages such as it has lower heat dissipation, high power density, has lower weight for similar PMSM motor, it is more efficient. Even though the initial cost of BLDC motor is more but its lifespan and its maintenance cost makes it better for the long run.

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