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Performance Analysis of Electric Vehicle Based on Various Working Scenarios

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Abstract

With a considerable capability to decarbonize the transportation sector, electric vehicle (EV) has successfully found its place in the field of mobilization with the inclusion of battery and an electric motor in the vicinity of the conventionally utilized fuel-derived engines. These motor and other components vary the performance of the vehicle under various working scenarios. Predicated on this concept, this paper is intended to present an overview of the various components that are used inside an EV. The paper focuses on the implementation of the most simple and low run time model of EV with both DC and Brushless DC Motor by using MATLAB Simulink software. In addition to this, a mathematical analysis of the system is included to depict the prominence of vehicle dynamics in the determination of the rating of the motor. From the simulation results, it was found that Brushless DC Motors are more efficient, easily controllable, more reliable, and consume less power than that of DC motor.

Disciplinary: Electric Vehicle Engineering (EVE); Automotive Engineering.

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1. Introduction

Mobility has always been an essential part of our life and to ease up this mobilization Vehicles have always come to our rescue in various forms. But with making our life simpler it has also damaged our surroundings. According to the latest Review of World Energy 2019 presented by the British Petroleum company [1] shows that total global reserves, by fossil fuel will be exhaust between 2066-2069. In this fast depletion, Vehicle also has some of its contributions due to the presence of Internal combustion engines in vehicles that uses fossil fuels to run. This depletion has led to an increase in the cost of fuel. Also, the use of fossil fuels has several environmental impacts, such as air pollution and global warming, as depicted by Martins et al. [2, 16]. Thus, with rising difficulties in the discovery of reservoirs of fuels under the earth, the need to reduce and replace the use of fossil fuel is increasing day-by-day. One such innovation involves the development of Power-driven vehicles or the inclusion of electric motors in place of the conventional fuel-driven vehicle.

Power-driven mobility or Electric Vehicle (EV) has reaped much more attention from both industry and academia, due to its advantages [3]: Clean (zero-emission and zero-pollution), the accommodation of avail and design (exhibits drive efficiency, distance covered and time to charge), cost- efficacious, good connectivity, etc. The inclusion of electric motors can be easily done in any type of vehicle, i.e., car, scooter, auto-rickshaw, etc. Moreover, EV includes are not just limited to roads. They have also become a prominent part of railways, sea-ways, and even in the sky as electric aircraft and satellites.

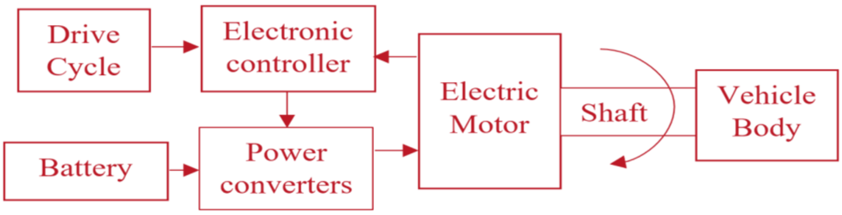

Figure 1 General Block Diagram for EV

Figure 1 shows the general block diagram of EV having different controllers, an electric motor, battery, power converters, and vehicle body [4]. The Integration of all these units is necessary to run the vehicle. In EV, batteries are utilized as the main energy source of the vehicle and supply the requisite amplitude of energy to the motor, which as a result runs the vehicle. Batteries are connected to the motor through various Power converters and controllers that help in controlling and optimizing the flow of power between the two. Lastly, the mechanical output from the motor is supplied to the wheel through the driving shaft present in the motor that helps the wheel to rotate. As presented by Bhatta et al., 2019 and Anurag and Date, 2015, to date EV's are making use of the electric motors, e.g., DC Motor, Brushless DC (BLDC) Motor or Permanent magnet Brushless DC (PMBLDC) motor, Induction (AC) Motor, Permanent magnet Synchronous motor or PMSM and Switched Reluctance motor (SRM) [5, 6]. Each of these motors has different performance parameters under different conditions. Based on this concept, the performance of DC and BLDC motors in an EV is analyzed and presented in this paper.

To date, EV's are making use of various electric motors. Each of these motors has a different working principle, constructions, and features when integrated with EV. Based on their pros and cons, they have found their application in EV as per the load requirements. This paper has explored the idea of the Integration of two different motors in vehicles i.e., DC Motor and BLDC Motor, and their performance is studied in detail.

Two key elements of power-driven mobility are Battery and the Electric motor. Now there are various motors used in EV. Predicated on this concept, analysis of the performance of DC motor and BLDC motor inside the EV is done in this paper. Also, when the vehicle is under operation battery continuously discharges. Thus, the study of the state of charge of battery before and after operation of the vehicle is also done. For proper analysis, two different drive cycles (steady-state cycle and transient cycle) are taken under consideration. A feed-forward loop is also added to analyze the impact of Regenerative Braking on the motors are also taken under analysis.

For this paper, a simulated model of EV was developed using MATLAB Simulink R2018a (2018 Edition) software. EV's with two different motors, that is, DC and BLDC motor, at two different drive cycles, are taken into consideration and are studied in detail.

2. LITERATURE REVIEW

A profound study of past articles and papers have been done for the prosperous development of this paper. The vision of the research is supported by a literature-driven methodology carried out to unravel the relevant technologies and methodologies.

Table 1: Literature survey.

Author	Objective	Key Findings
Xin et al. [9]	SOC determination	The authors compared the Extended Kalman Filter algorithm with Kalman Filter and Coulomb counting.
Bhatta P. N. et al. [5]	Analysis of efficiency, power density, and size of EV	For all the characteristics PMBLDC motor shows the best results.
Warake et al.[8]	Regenerative braking in EV	The proposed analysis is based on the experimental set-up and simulated model developed using MATLAB software.
Kusum and Parveer [15]	Powertrain components	The proposed method includes designing and simulation of EV using MATLAB software.
Tiwari and Jaga [4]	Component study of EV	Comparative study of various components of EV is done.
Abulifa et al. [10]	SOC determination	The paper presents the simulated model for EV developed using MATLAB Simulink Software.
Porselvi et al. [12]	Motor rating analysis	The power rating of EV is found referring to the vehicle dynamics and speed of the motor is found using ANSYS Maxwell Software.
Berjoza and Jurgena [14]	Vehicle dynamics analysis	The paper presents a methodology to determine vehicle dynamics based on the weight of the battery.
Lulhe and Date [13]	Speed controller and PWM inverter designing	The paper includes the modeling and simulation of EV using induction motor in MATLAB Simulink software.
Maini et al. [3]	EV Characteristics	The paper outlines the main concept behind the growth of EVs.

Based on the literature survey summarized in Table 1, an appropriate design mechanism of Electric Vehicle and Integration of Various components that are used in an EV structure was examined in brief. It was found that the simulation model previously [10], [13] and [15] in MATLAB uses Simulink block-sets in which the resulting diagram obtained is equivalent to its mathematical model. For a change, in this paper, the simulated model was prepared using Simscape Block-sets that has a physical modelling approach and is analogous to connecting real components that helps in understanding the physical connections between two components and gives an appropriate picture of the physical system. An appropriate analogy of vehicle dimension was obtained and is depicted in this paper, from [12, 13]. Also, by considering the analysis [14], the weight and the capacity of the battery is considered. Based on Xin et al. [9], the SOC estimation is done using the Coulomb counting method. To extend the analysis [8], this paper includes an analysis of the impact of regenerative braking using various drive cycles.

3. Materials and Methodology

3.1 Vehicle Resistance

Forward movement of the vehicle is opposed by the various resistive forces [7]. These resistive forces include,

3.1.1 Tire Rolling Resistance

The force exerted against the rotational movement of the tire on the road is known as the tire rolling force. It can be expressed as,

$$F_r = m_v g C_R \cos\alpha \quad (1)$$

Here, m_v is the mass of the vehicle, g is the gravitational acceleration, C_R is the rolling resistance coefficient and α is the road/ grade angle.

3.1.2 Aerodynamic Drag

Atmospheric air around is always pushed by a running vehicle but this air does not move out instantly and thus produces a resistive force known as aerodynamic drag/ resistance. This force can be expressed as,

$$F_a = 0.5\,\rho A_f C_D (V_v + V_0)^2 \quad (2)$$

Symbol V_v is the vehicle speed, C_D is the aerodynamic drag coefficient, A_f is vehicle frontal area, V_0 is the component of wind speed on the vehicle's moving direction and ρ is the air density.

3.1.3 Grading Resistance

A force is produced due to the mass/weight of the vehicle while moving on a sloping road. This force experienced by the vehicle on the sloppy road is known as Grading Resistance. Mathematically, the Grading force can be expressed as

$$F_g = m_v g \sin\alpha \quad (3).$$

3.2 Regenerative Braking

Kinetic energy lost 10-15% during braking or deacceleration can be regained by the electric motor inside [8]. The energy so regained is converted to electrical energy and is fed back into the battery source. This could thus lead to an increase in efficiency and charge of the battery. This process of regaining the energy lost during acceleration comes under the regenerative energy recapture system.

3.3 State of Charge Estimation

Batteries have an inhibited amplitude of energy and discharge continuously when the vehicle is under operation. In this paper, we have used the Coulomb counting method for SOC estimation [9]. It is defined as the ratio between the residual charge available $Q(t)$ and the nominal capacity $Q_{nominal}$ in SOC [10].

$$SOC = \frac{Q(t)}{Q_{nominal}} \quad (4)$$

3.4 Drive Cycle

The driving cycles are basically the speed Vs time graphs having a fixed schedule, that are used to estimate the fuel or power consumption of the vehicle [11]. Based on the variation of speed with time the vehicle can be classified as steady-state drive cycle and transient drive cycles. In the steady-state drive cycle, vehicle speed remains almost constant with time while in the transient drive cycle, speed is more or less continuously varying with time.

This study was conducted for both types of cycles. For transient cycle, standard drive cycles, Artemis Motorway 130 pre-post Cycle was considered. For the steady-state cycle, a reference drive cycle was developed using signal builder block in MATLAB Simulink Software which is shown in Figure 2.

Maximum run Time: 1000 sec,

Maximum Speed: 30 m/sec,

Total distance covered: 29.97 Km.

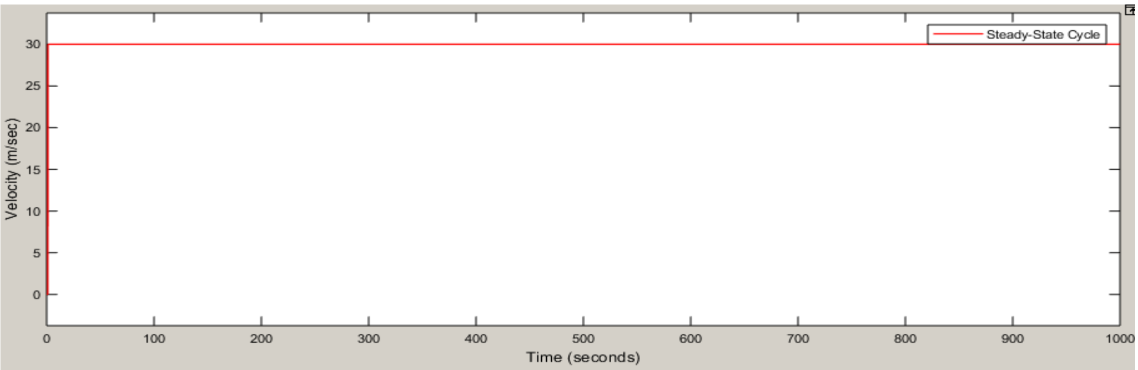

Figure 2: Steady-state drive cycle.

4. Mathematical Analysis

The calculation of the input values that are assigned to each component Integrated to develop the Simulink model of EV is discussed in [12-15] and are summarized in Table 2.

Assume, Total no. of passengers = 4, and each passenger's weight = 65 Kg. Thus, Total Passenger Weight = 4*65 = 260 kg. Now, assume the Weight of the battery = 290 Kg, Hull weight = 400 Kg, and Motor weight = 50 kg. Then, the mass of the vehicle m_v can be defined as the sum of total passenger weight, weight of the battery, hull weight, and motor weight, i.e.,

$$m_v = total\ passenger\ weight + weight\ of\ battery + hull\ weight + motor\ weight$$
$$= 260 + 290 + 400 + 50 = 1000 \text{ kg} \quad (5)$$

Now, take grade angle α = 0^0, rolling resistance coefficient c_r = 0.015, gravitational acceleration g = 9.81 m/s^2, air density ρ = 1.225 kg/m^3, vehicle speed V_v = 42 m/sec = 151.2 km/hr, component of wind speed V_0 = 3 m/sec, and $A_f C_D$ (for executive car) = 0.55 m^2.

Then, from Equations (1), (2), and (3), the values of Rolling resistance, Aerodynamic drag and Grading resistance can be found as

$$F_r = m_v g C_R \cos\alpha = 1000 \times 9.81 \times 0.015 \times \cos 0^0 = 147.15 \text{ N} \quad (6),$$

$$F_a = 0.5\,\rho A_f C_D (V_v + V_0)^2 = 0.5 \times 1.225 \times 0.55 \times (42+3)^2 = 682.171 \text{ N} \quad (7),$$

$$F_g = m_v g \sin\alpha = 0$$

$$\therefore \text{as } \alpha = 0, then \sin\alpha = 0 \quad (8).$$

So, the total resistive force is again the sum of rolling resistance, aerodynamic drag and grading resistance i.e.,

$$F_{total\,resistive} = F_r + F_a + F_g = 147.15 + 682.171 + 0829.321 \text{ N} \quad (9).$$

And Total tractive power is

$$P_{total\,tractive} = \frac{F_{total\,resistive} \times V_v(in\ km/hr)}{3600} = \frac{829.321 \times 151.2}{3600} = 34.831 \text{ KW} \quad (10).$$

Total mechanical power P_{mech} or rated power output is defined as the ratio of Total tractive power divided by transmission efficiency (η) and can be expressed as

$$P_{mech} = \frac{P_{total\,tractive}}{\eta} = \frac{34.831}{0.86} = 40.5 \text{ KW} \quad (11).$$

Further assuming gear ratio = 3.7 and the radius of the wheel r_w = 0.3 m. Then, Vehicle speed in rpm (Revolution per minute) can be defined as

$$V \text{ (rpm)} = \frac{V_v(in\ m/sec) \times 60}{2\pi r_w} = \frac{42 \times 60}{2\pi \times 0.3} = 1336.364 \text{ rpm} \quad (12).$$

The Rated Speed of the Motor is

$$S_M = V \text{ (rpm)} \times Gear\ Ratio = 1336.364 \times 3.7 = 4944.5 \approx 5000 \text{ rpm} \quad (13),$$

and

$$\text{Maximum Torque} = \frac{P_{mech} \times 60}{2\pi \times S_M} = \frac{40.5K \times 60}{2\pi \times 5000} = 77.3 \approx 80 \text{ N-m} \quad (14).$$

Table 2: Input Parameters

MOTOR SPECIFICATIONS (DC MOTOR)		
1	Rated power output	40.5 KW
2	Rated input voltage	300 V
3	Rated No load speed	8000 rpm
4	Rated speed	5000 rpm
MOTOR SPECIFICATIONS (BLDC MOTOR)		
1	Rated power output	40.5 KW
2	Maximum Torque	80 N-m
3	Motor Efficiency	96%
BATTERY		
1	Battery rating (in Ah)	80 Ah
2	Supply Voltage	300 V
VEHICLE DYNAMICS		
1	Gear Ratio	3.7
2	Wheel radius	30 cm
3	Transmission efficiency	86 %
4	Mass of the Vehicle	1000 Kg
5	Inclination	0^o

The discussed mathematical analysis defines the dependence of the rating of the motor to the vehicle dynamics. Thus, this can be understood that Vehicle dynamics are a prominent part in the determination of the rating of the motor.

5. EXPERIMENTAL ANALYSIS

This section includes the simulated model (experimental analysis) of EV with both DC Motor and BLDC Motor and also includes various subsystems that are developed using MATLAB Simulink (Sim-scape) software tool.

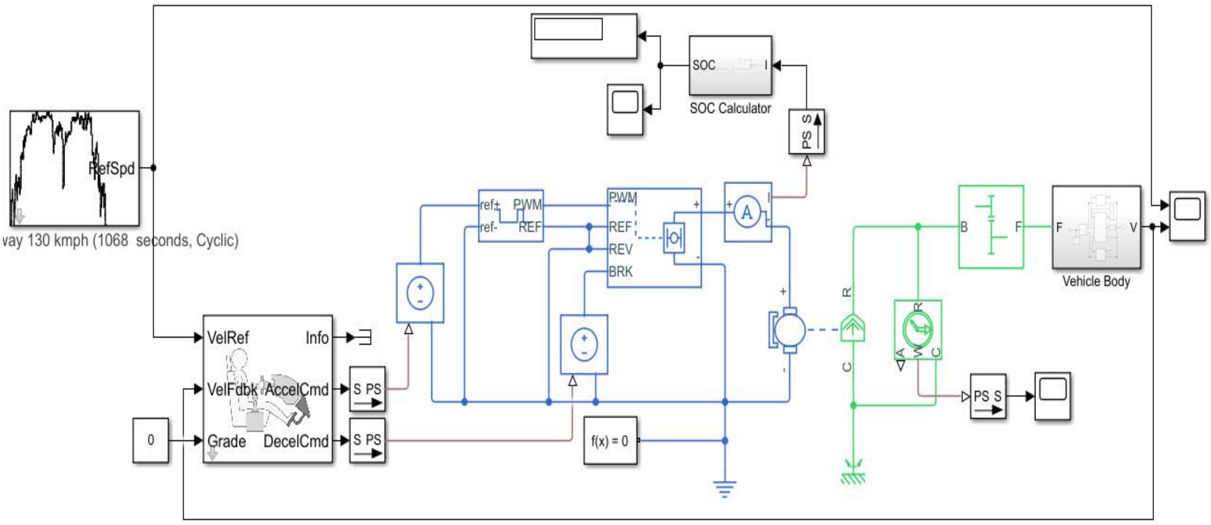

Figure 3: Simulink Model for DC Motor

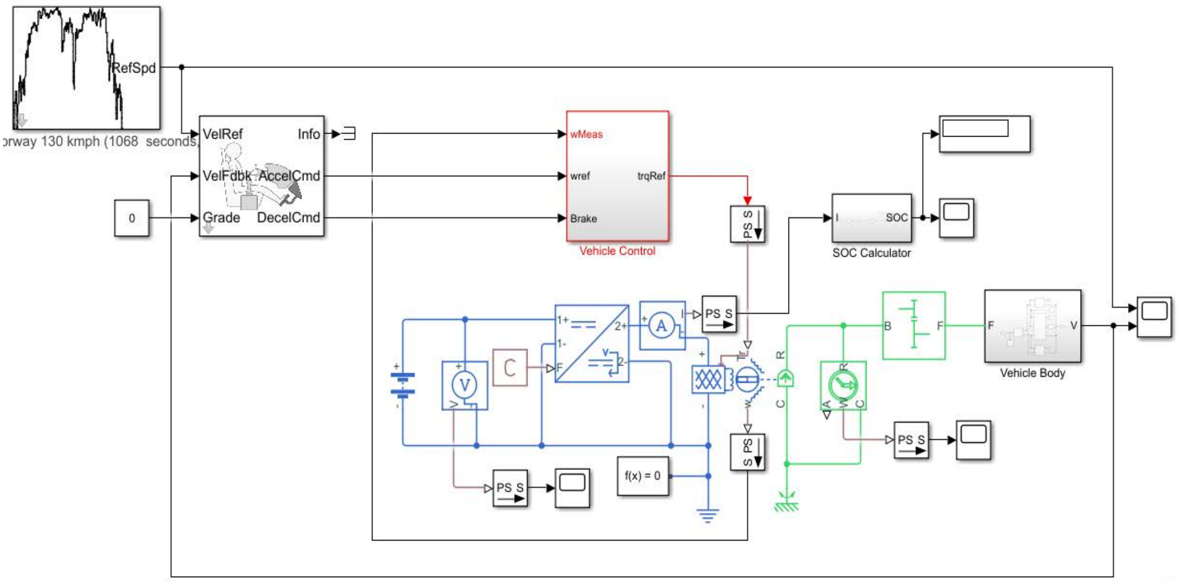

Figure 4: Simulink Model for Brushless DC Motor

In the Simulink model shown in Figure 3, for DC motor the speed of the motor is controlled by connecting a Speed controller or PI Controller through a PWM voltage controller and H-Bridge. Both these blocks are available in the Simulink Library. The H- Bridge block in MATLAB is designed such that, by default, it provides regenerative braking to the system. For the BLDC motor shown in Figure 4, the speed of the motor is controlled through an electronic controller and power input to the motor is supplied through a dc/dc converter which allows bi-directional flow of current. The simulated model for the electronic controller/ Vehicle speed controller shown in Figure 5 consists of speed controller, braking system and a feed-forward network to provide regenerative braking to the system.

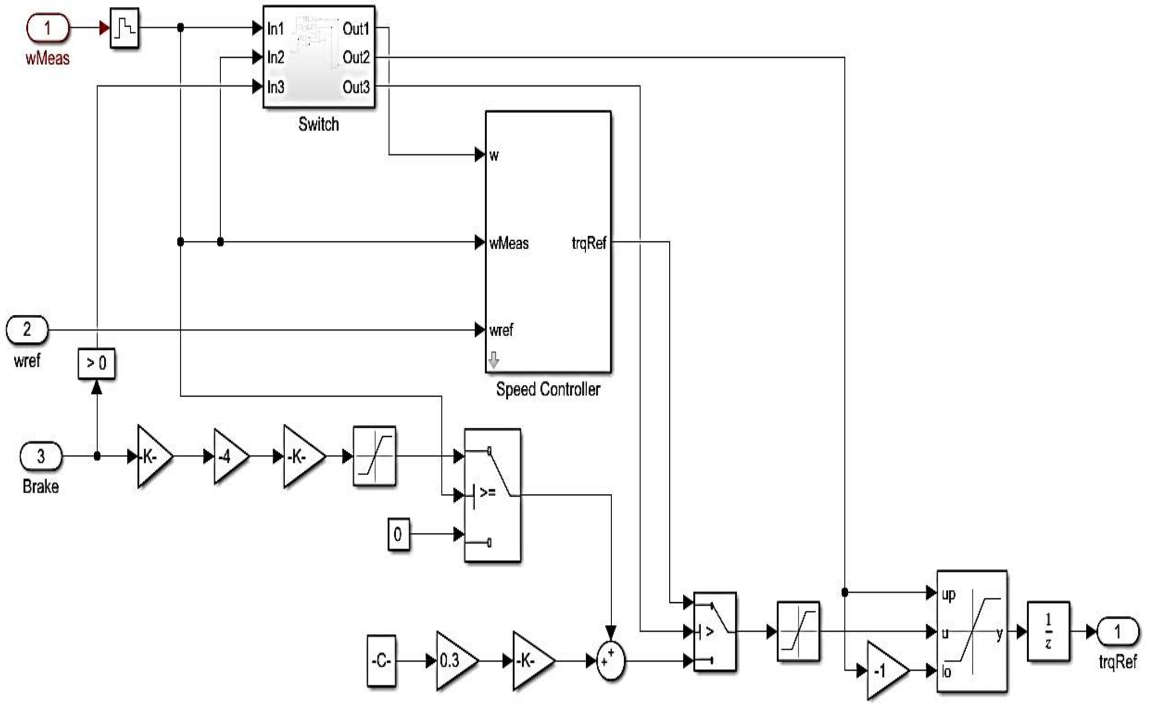

Figure 5: Simulink Model for Vehicle speed controller.

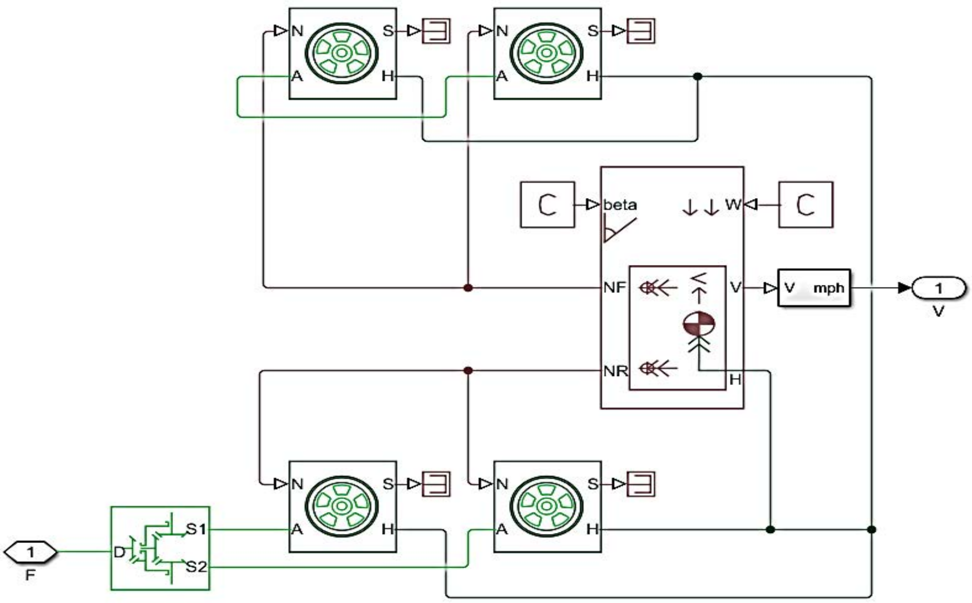

Figure 6: Simulink Model for Vehicle Body.

Vehicle parameters such as Vehicle resistance, the mass of the vehicle, the radius of the wheel, gear ratio, etc. are assigned at the Simulink model shown in fig 6. This Simulink model consists of wheels that are connected to the motor through the gear and differential.

6. Observations

6.1 Drive Cycle analysis

This includes the curve for Drive cycle input for both steady-state and transient cycle input (Artemis cycle) Vs Vehicle speed for both DC and BLDC motor.

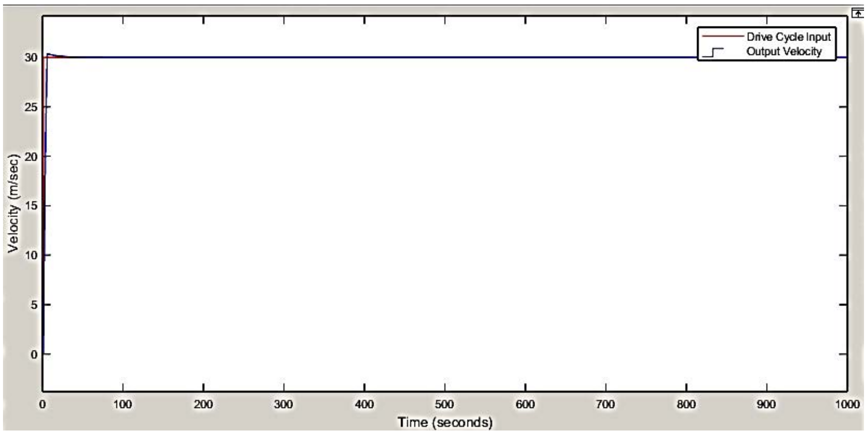

Figure 7 DC motor Input Vs Output Velocity Graph for Steady – State Drive Cycle

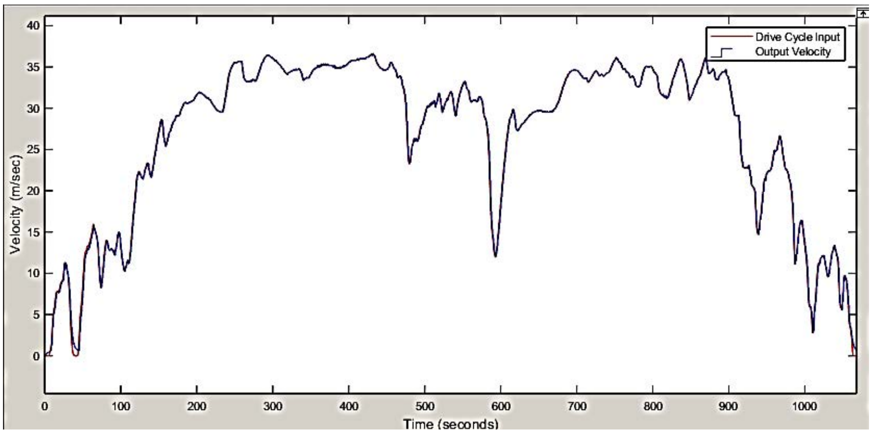

Figure 8 DC motor Input Vs Output Velocity Graph for Artemis Motorway Cycle

According to the simulation curves for transient and steady-state drive cycles, i.e. Figures 7 and 8 obtained for DC motor, it is found that the drive cycle speed and vehicle speed are almost overlapping each other. Hence, it is understood that the vehicle speed and the drive cycle speed for DC motors were almost the same. At some points in drive cycle curves, there is a slight variation found between the drive cycle and vehicle speed. This is due to the motor/vehicle inertia.

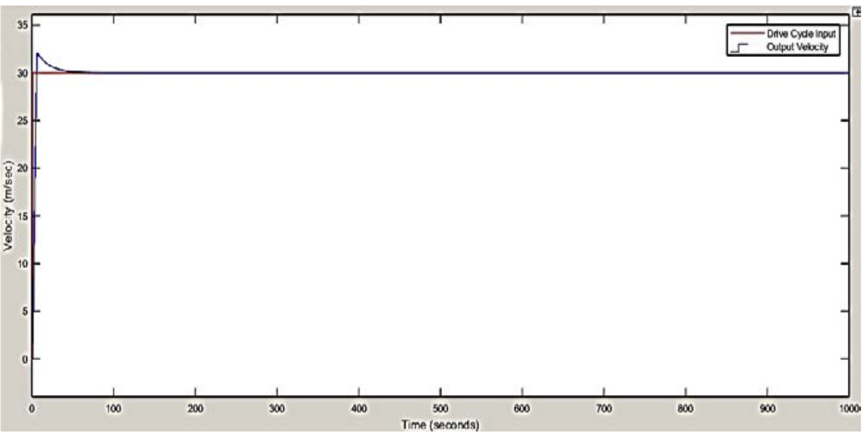

Figure 9 BLDC motor Input Vs Output Velocity Graph for Steady-State Drive Cycle.

According to the simulation curves for transient and steady-state drive cycles, i.e. Figures 9 and 10, obtained for BLDC motor, it is found that the drive cycle speed and vehicle speed are almost overlapping each other. Hence, it is understood that the vehicle speed and the drive cycle speed for

BLDC were almost the same. At some points in drive cycle curves, there is a slight variation found between the drive cycle and vehicle speed. This is due to the motor/vehicle inertia.

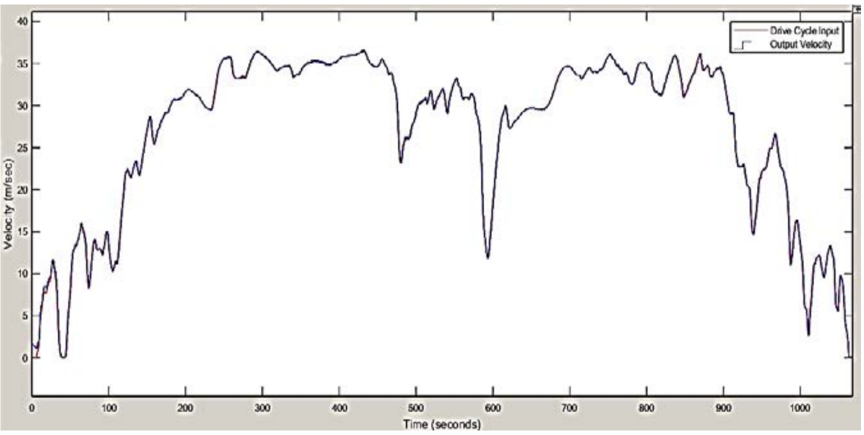

Figure 10: BLDC motor Input Vs Output Velocity Graph for Artemis Motorway 130 cycles.

6.2 State of Charge

In this section comparison of SOC of DC motor and BLDC motor is done for the same type of drive cycle inputs.

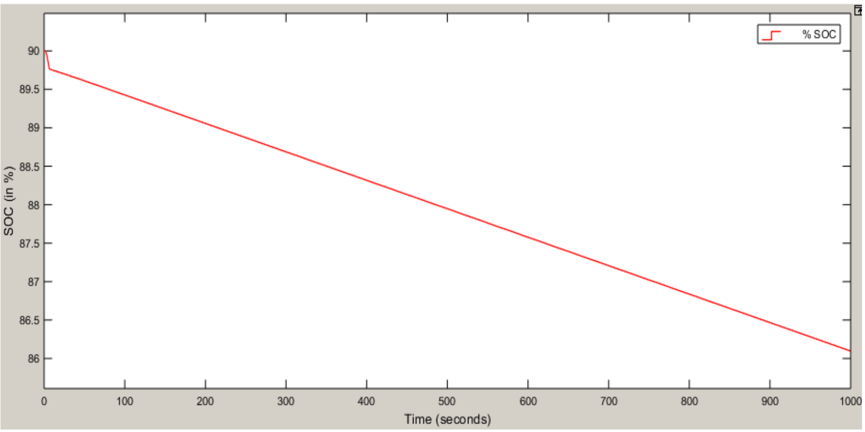

Figure 11 SOC of Steady-state cycle for DC Motor.

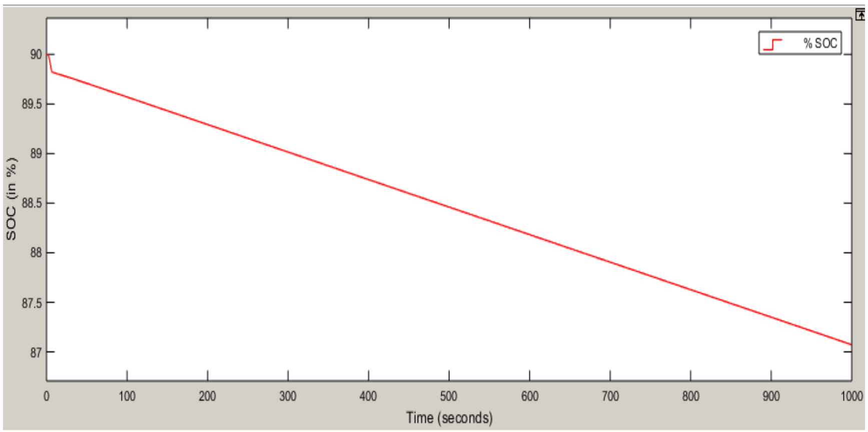

Figure 12 SOC of Steady-state cycle for BLDC Motor

Figures 11 and 12 include the curves of Steady-state cycles for DC and BLDC motor respectively. It is seen in the curves that the rate of discharge is almost the same for both DC and BLDC motor, for a similar drive cycle. At the time from 0 to 1 sec, the vehicle speed is increasing so power consumption is slow but at a time greater than 1 sec as the vehicle gains a constant speed of

30 m/s the power consumed by the vehicle is higher than the before, and the thus, the rate of discharge of vehicle battery also increases.

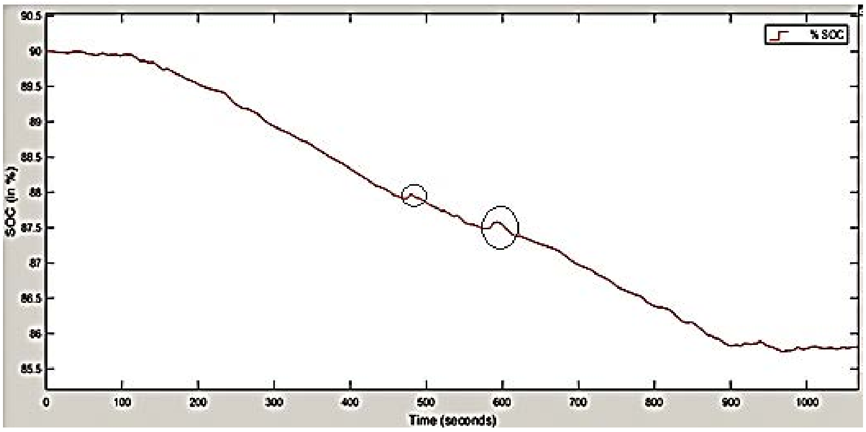

Figure 13 SOC of Artemis motorway cycle for DC motor.

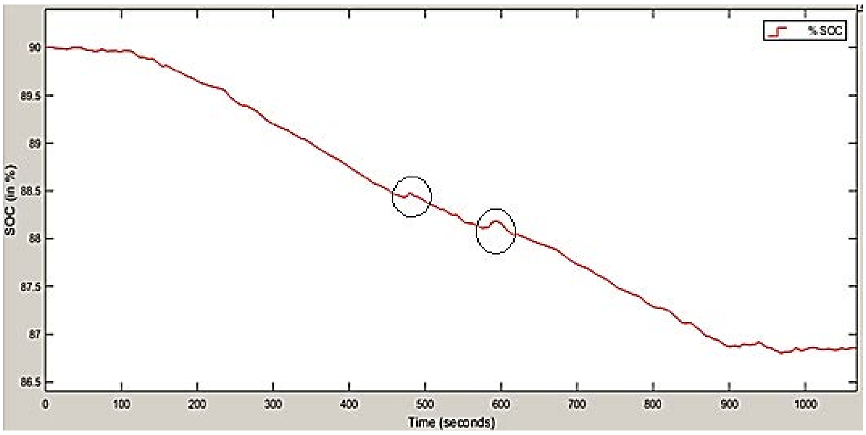

Figure 14 SOC of Artemis motorway cycle for BLDC motor.

Figures 13 and 14 include the curves of Artemis Motorway cycles for DC and BLDC motor respectively. It is seen in the above curves that the rate of discharge is almost the same for both DC and BLDC motor, for a similar drive cycle. From the SOC curve for Artemis Motorway cycle, it is also observed that at some point encircled in Figures 13 and 14 where the vehicle deaccelerates, there is a slight increase in SOC. This is due to the effect of regenerative braking applied.

6.3 Power Curve

When the electrical power is fed to the motor, then this electrical input is converted to the mechanical power that helps in rotating the shaft. In between this conversion from electrical input to mechanical output some energy is lost due to various losses inside the motor, such as, iron loss, copper loss, Stray loss, brush friction loss, etc. due to which there is some amount of variation in electrical input and mechanical output. This variation curves between the Electrical input and mechanical output of the EV for both DC and BLDC motor when derived at different drive cycle is studied below and the result obtained is discussed after that thereon.

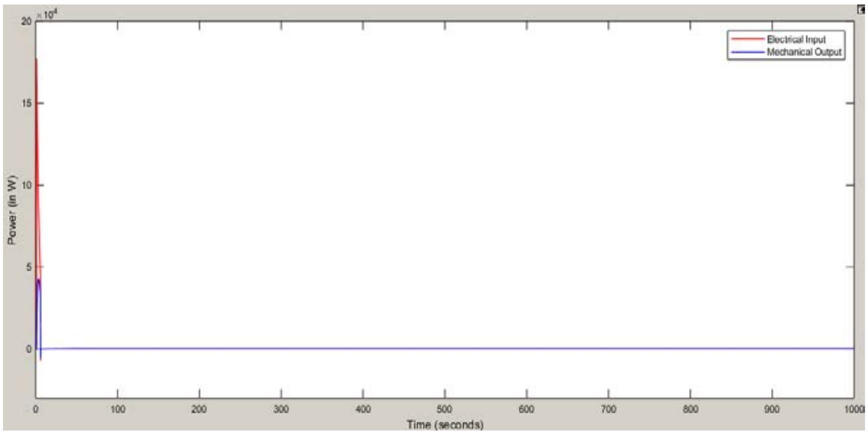

Figure 15 Power curve of steady-state drive for DC motor.

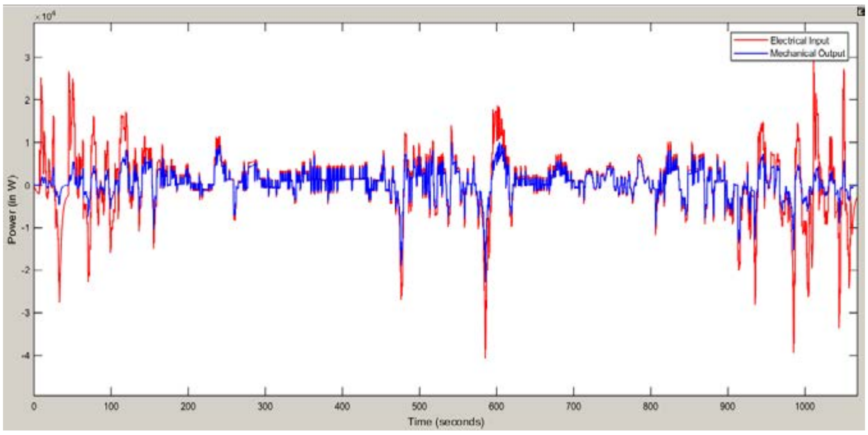

Figure 16 Power curve of Artemis motorway cycle for DC motor.

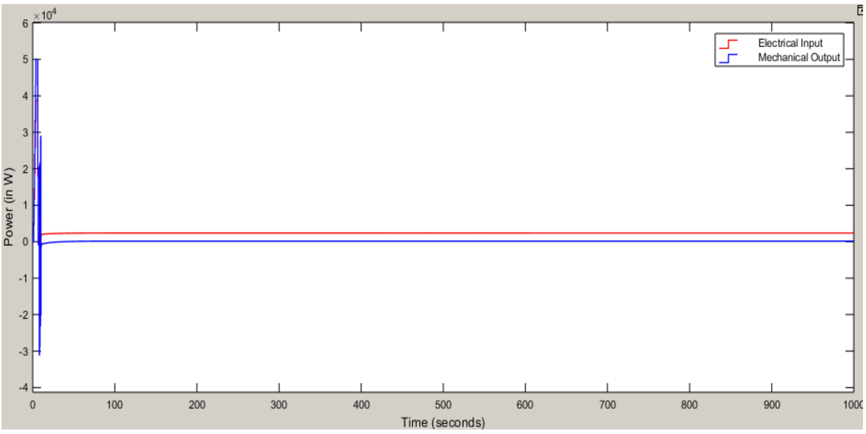

Figure 17 Power curve of the steady-state drive for BLDC Motor

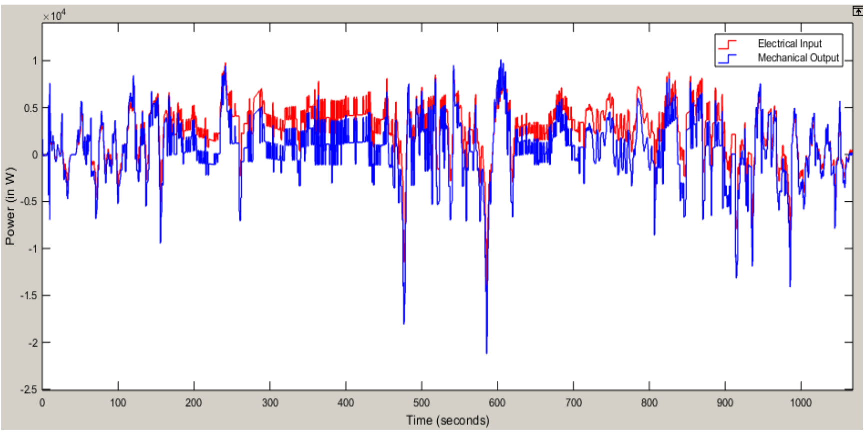

Figure 18 Power curve of Artemis motorway cycle for BLDC motor.

It is found from the curves of electrical input Vs mechanical output power (i.e. from Figures 15 to 18) that, in BLDC motor, the variation is less between the two curves compared to that of DC motor. This means that losses are less in the BLDC motor compared to that of the DC motor. Hence, this justifies the high efficiency of the BLDC motor compared to that of the DC motor.

Based on the Modelling and the simulation of the Electric vehicle done using MATLAB Simulink Software, the performance and impact of various parameters on EV are verified. The outcomes of the parameters so assessed through the simulation are discussed in Table 3.

Table 3: Observation table for drive cycle

Parameter	DC MOTOR		BLDC MOTOR	
	Artemis Motorway 130 Cycle	Steady-State Cycle	Artemis Motorway 130 Cycle	Steady-State Cycle
Time (sec)	1068	1000	1068	1000
Maximum speed (m/s)	40.44	40.44	41.78	41.78
Maximum speed (rpm)	7880	7880	8140	8140
Standard distance covered (km)	28.77	29.97	28.77	29.97
Observed distance covered (km)	28.74	29.92	28.76	29.94
Initial State of Charge (%)	90	90	90	90
State of Charge (%)	85.81	86.1	86.86	87.07

SOC as mention in observation Table 3 shows that the amount of charge lost with DC motor is greater than that of BLDC motor, or, for the steady-state cycle, SOC of DC motor is 86.1% whereas for Brushless DC motor it is 87.07% which is lesser than DC motor. Similarly, in Artemis Motorway cycle for DC motor SOC is 85.81 % and for BLDC motor is 86.86%. Thus, the power consumed by the BLDC motor is less than in comparison to that of the DC motor.

Table 4: Vehicle mass and state of charge

Vehicle Mass (Kg)	State of Charge (in %)	
	For DC Motor (Artemis Motorway 130 Cycle)	For BLDC Motor (Artemis Motorway 130 Cycle)
850	86.92	88.01
1000	85.81	86.86
1100	84.79	85.89

From the observation Table 4, it is found that as the mass of the vehicle is increased for both DC and BLDC motor the amount of charge present in the battery reduces. This means that for propulsion of heavier vehicle more power is consumed compared to that of the power consumed for a light vehicle.

7. Conclusion

This paper presents an overview of the various components that are used in EV structures and how they are integrated together inside the vehicle. The shaped apparition is converted into a realistic baseline scenario by focussing on the Simulation and modeling of Electric vehicles with DC and BLDC motor for various drive cycles using MATLAB Simulink R2018a software. The vision of the research is supported by a literature-driven methodology carried out to determine the relevant technologies. The simulated model of the electric vehicle was successfully developed and is included in this paper. Comparing the results obtained for both the motor, it was found that BLDC Motor is more efficient, easily controllable, more reliable, and consumes less power than that of DC motor. For both the motor the vehicle speed and drive cycle speed was found to be almost the same. Also, the inclusion of regenerative braking shows that some amount of energy lost during deacceleration can be regained and fed-back to the battery. Thus, this concludes that with improvement in the regeneration braking system, the efficiency can be improved to a lot more level. The impact of the mass of vehicles on power consumption is also observed which shows that power consumption of the vehicles increases with an increase in the mass of the vehicle. Also, through the mathematical analysis of the system, it was found that the Vehicle dynamics are a prominent part in the determination of the rating of the motor. The presented work confirms that in near future with development in some performance parameters, Electric vehicles could govern the mobility market.

8. Availability of Data and Material

Data can be made available by contacting the corresponding author.

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