Performance Study of Different Types of Battery of Electric Vehicles Using MATLAB Simulink

Md. Sohel Siddequy[1], Sheik Erfan Ahmed Himu[2], Arafat Ibne Ikram[3], Fahim Abrar[4],
S. M. Shahriar Iqbal[5], Md. Ziaur Rahman[6], Tasnia Fahrin Choity[7]
[13456]*Department of Electrical and Electronic Engineering, International Islamic University Chittagong. Chattogram, Bangladesh*
[2]*Department of Electrical and Mechanical Engineering, Nagoya Institute of Technology. Nagoya, Japan*
[7]*Department of Computer Science and Engineering, International Islamic University Chittagong.Chattogram, Bangladesh*
Email: [1]sohelsiddequy35@gmail.com, [2]erfanhimu@gmail.com, [3]arafatibne.ikram@gmail.com,
[4]fahimabrar000@yahoo.com, [5]shahriareee17@gmail.com, [6]ziaur24.iiuc@gmail.com, [7]tasniachoity@gmail.com

***Abstract*—Since the advent of the Industrial Revolution, fossil fuels and internal combustion engines have played a fundamental role in meeting transportation and energy needs. However, the extensive reliance on fossil fuels over the past two centuries has resulted in dire consequences, such as global warming, environmental disruption, glacier melting, rising sea levels, and droughts. Consequently, scientists have been actively exploring alternative solutions to replace fossil fuel-based transportation systems. Electric vehicles (EVs) have emerged as a pivotal solution to address the existing challenges in transportation systems. Although the concept of EVs has existed for some time, the widespread production and adoption of fully electric cars was hindered until the early 21st century owing to the unavailability of suitable batteries or energy storage systems. The efficacy of EVs relies heavily on their energy storage systems. In this article, we evaluate various battery types (including nickel metal hydrate, zinc hybrid cathode, lead acid, and lithium-ion) in the context of EV performance, using MATLAB Simulink. A MATLAB Simulink-based electric vehicle model was employed to assess battery performance. Our analysis reveals that lithium-ion batteries demonstrate superior performance metrics, including a specific energy ranging from 100-275 WH/kg, energy density of 200-235 Wh/L, specific power of 350-3000 W/kg, cell voltage of 3.6V, and cycle durability of 500-3000. Furthermore, we consider the typical cost of these batteries, noting that lead-acid batteries are relatively more affordable than other options available in the market.**

***Index Terms*—Electric Vehicle, Fuel Cell, Ni-MH, Li-ion, PMSM, Green Transportation System, HEV, FECV.**

I. Introduction

Over the last few years, we have been witnessing a growing shift in the transportation sector towards green energy [1]. EV plays the most important role in this change. It is expected that the total share of BEV will rise from 2% in 2016 to 30% in 2030 [2]. As of 2020, the total sales share of BEV stands at 9% with a total figure of around 16.5 million cars on the road [3]. Among many models available in the market Tesla Model 3 and Toyota Leaf are the most popular models [4]. BEV will significantly take part both in developed and developing countries within the next couple of years towards the greener transportation trend [5]. However, BEV has some limitations like Low production rate [6], Price and other factors [7], Low range, Long charging speed [8], Not being completely green [9], Possible battery shortage and so on. These limitations are pushing scientists for a better solution in the transportation industry. Some are thinking fuel cells might be the solution in this case [10]. FCVs fuelled by pure hydrogen release no toxic emissions, which contribute to smog and dangerous particles in the United States. Some pollutants are produced when hydrogen is produced from fossil fuels, although they are far fewer than those produced by conventional cars [11].

Previously, the majority of researchers worked on BEVs while very few worked on FCEVs. Author Thanh Anh Huynh et al. investigated the electromagnetic and thermal characteristics of a few traction motors for EVs in 2018. The engines are tested using two separate driving cycles, one for highway driving and one for city driving [12]. A research group, Swaraj Jape and Archana Thosar et al. (2017) consider various types of electric motors based on specific factors that should be considered before selecting a specific motor composition for EV application. A few parameters have been used to classify the examination [13]. 2017's Gagandeep Luthra et. al. has highlighted the importance of electric motor drives, which are essential components of electric vehicles. Here, an effort is planned to examine various types and characteristics of electric motor drives used in electric vehicles [14]. In a case study using a Brushless DC motor for an electric car, T. Porselvi et al. (2017) [15] showed the method for selecting the right rating for electric motors. In this study, factors related to the vehicle are taken into account while selecting the optimal electric motor to provide the necessary torque and power for traction. In addition, making a wise rating choice helps to ensure that you use an electric motor of the right size. Ahmed A. AbdElhafez et al., 2017 consider several machine approaches for High-Speed Traction applications, including traditional techniques such as induction machines, permanent magnets, and SR and DC machine techniques. The correlation tends to different HST zone plan parameters such as cost, quality, competency, fault torque, non-critical failure capacity, and power density [16], [17]. There are various reasons why you would choose to conduct your research in a fuel cell-based electric vehicle (FCEV). Zero

979-8-3503-1965-1/23/$31.00

emissions, increased range, faster refueling, versatility, scalability, energy security, and technological advancements. It's also worth noting that FCEVs face significant hurdles, such as limited hydrogen refueling infrastructure, greater upfront costs than conventional vehicles, and the necessity for sustainable hydrogen production technologies. However, by undertaking research in this field, you can help to address these issues and promote the wider use of FCEVs in the future.

The primary goals of this research are to investigate fuel cell-powered electric vehicles, as well as to investigate various electric vehicle motors. To create an FCEV system based on PMDC and PMSM. To examine the performance of the PMDC and PMSM in FCEV.

II. FCEV Simulink Model

We have designed our proposed system in MATLAB Simulink. The block diagram of an FCEV is shown in Fig. 1.

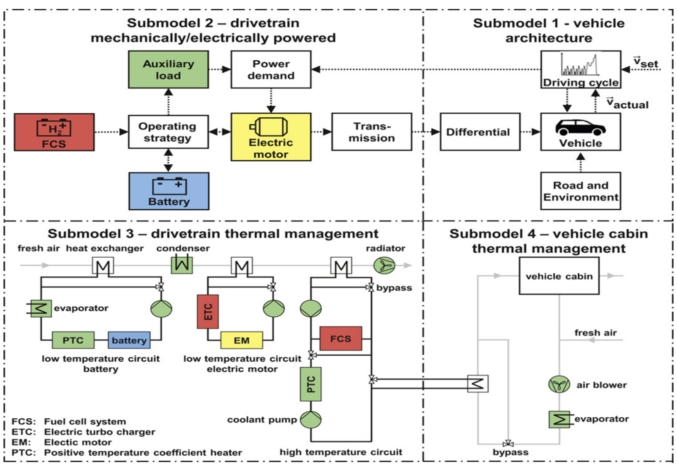

Fig. 1. Block diagram of an FCEV [18]

An FCEV is mostly similar to a BEV except for the fuel cell chamber. A BEV uses power from the battery while FCEV harnesses the power of the hydrogen fuel. The figure stated in Fig. 1 depicts the key mechanism of an FCEV. In this figure, submodels 1,3 and, 4 are the same as a traditional vehicle. Sub-model 2 which represents drivetrain is the key difference. In sub-model 2 we see that power is provided by the fuel cell stacks which run primary and auxiliary loads. Primary loads are the motors and braking system of the vehicle.
The important design parameters of the vehicle are given in Table I. The modeled system works as follows

Here, It first takes the reference velocity as an input and then generates the necessary acceleration and deceleration commands. The motor controller receives the acc and dece parameters. These parameters are used by the motor controller to generate a PWM signal and thus control motor current. The motor speed can be increased or decreased by controlling the motor current. The motor is linked to a gear, which is linked to the axle. The FCEV model is shown in Fig. 2. The vehicle model consists of 7 sub-models namely. These are:- Input arguments, Drivetrain, Motor control, DC motor, Sensors, Vehicle body, and Fuel cell. The sub-models are described below.

TABLE I. FCEV Parameters

Parameter	Specifications	Parameters	Specifications
Mass	600 kg	Incline angel	0.05 rad
Motor power	40 kW	Gear NF/NB	2
No of wheel	4	Controller	PI
Wheels per axle	2	kp	1
CG height	0.5 m	ki	30
Frontal area	2 m2	Fuel cell type	SOFC
Drag coefficient	0.4	Power	3 kW
Air density	1.18 kg/m3	Vdc	100
Pitch	not considered	No. of cells	119
Wheel radius	30 cm	Top	600 C
Average wind speed	2 - 5 m/s	Fuel supply pressure	1.35 (air): 1 (H2)

A. Input arguments

We have added 4 different ways to input reference velocity **'v'** and used a multiport switch to switch between the input values. The first way is to use a MATLAB predefined drive cycle source. There are many available drive cycles in MATLAB to choose from. The second way is to use a custom-defined reference velocity which is built with a signal builder block. This signal can also be generated using an Excel spreadsheet or by importing any other supported form of data. The third method is by using a slider gain, where the user defines the velocity by moving the cursor in the slider. The fourth format is by using simulation data from another simulation data through the workspace.
The input arguments subsystem is shown in Fig.3.

B. Drivetrain

Fig. 4 illustrates the drivetrain subsystem. The drivetrain basically simulates the situation of a driver who controls acceleration, deceleration, and other controls of the car. This subsystem takes reference and feedback velocity and produces necessary acceleration and deceleration commands. In this particular model, we can give the reference velocity in many different ways as we have stated earlier. That reference velocity is the main input of the drivetrain which is compared with the feedback velocity. Then based on the errors in the feedback a PI controller controls the vehicle by generating the required acceleration and deceleration commands.

C. Motor control

The motor controlling subsystem is shown in Fig. 5. The motor is basically controlled by the motor current. A pulse width modulated signal is generated from the acceleration and deceleration data which performs this controlling job. Acceleration command from the drivetrain is used to control the PWM generator. The deceleration command controls the brake of the vehicle. Both these signals are fed to the H-Bridge which ultimately produces motor current which controls the motor.

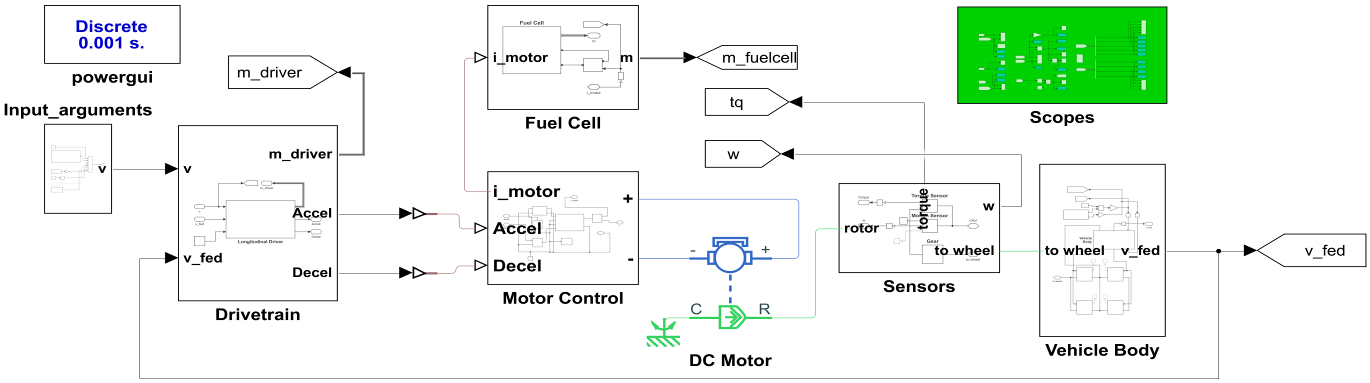

Fig. 2. Simulink model of the designed vehicle

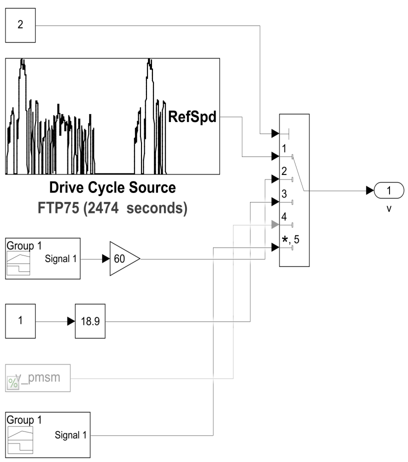

Fig. 3. Input parameters of the designed vehicle

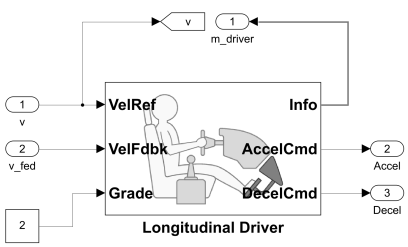

Fig. 4. Drivetrain model of the designed vehicle

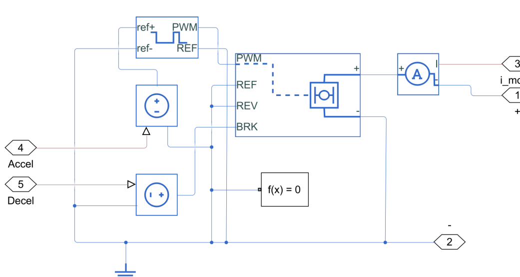

Fig. 5. Motror control mechanism of the designed vehicle

D. Fuel cell

The main component of the fuel cell subsystem is the fuel cell block. The specification for the fuel cell is given in I. From the mechanical data port, we get the different parameters of the fuel cell (Fig. 6) such as cell current, voltage, stack efficiency, flow rate, total stack consumption, and so on for analysis of the system.

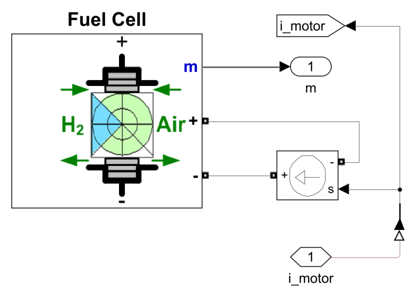

Fig. 6. Fuel cell model of the designed vehicle

E. Sensors

The sensor subsystem contains two mechanical sensors and the gear. The mechanical sensors are torque and motion sensors respectively for measuring torque, angular velocity, and angle of the system. It is shown in Fig. 7.

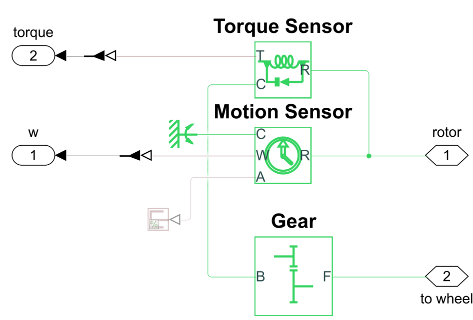

Fig. 7. Necessary sensors to measure the mechanical output of the designed vehicle

F. Scopes

This subsystem deals with taking all the parameters and visualizing and analyzing them in the report. All the variables

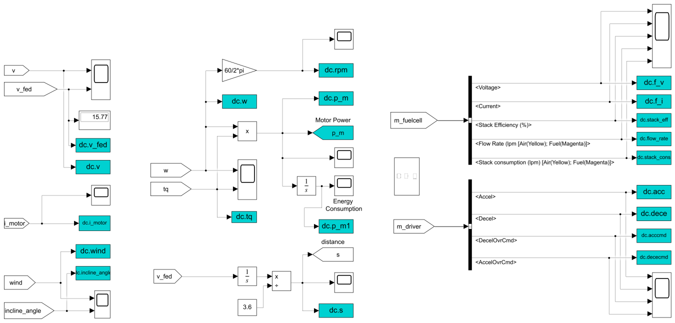

Fig. 8. Scopes of this model

of Fig. 8 are given in Table II. We showed the physical, mechanical, and electrical signals of different blocks. The physical signals are velocity and reference. Mechanical signals are the torque and speed of the motors. Electrical signals are voltage, current, power, etc.

It can be mentioned that some parameters like revolution per minute, energy consumption, power consumption, and distance are calculated from the initial parameters.

TABLE II. Scope signals and their meanings

Name	Meaning	Name	Meaning
V	Reference velocity	p_m	Motor power
v_fed	Velocity feedback	p_m1	Motor energy consumption
i_motor	Motor current	s	Distance traveled by the vehicle
wind	Wind speed	rpm	rpm of the motor
incline_angle	Incline angle of the road	m_fuelcell	Fuel cell outputs
w(omega)	Angular velocity	m_drivetrain	Drivetrain output
tq	Torque		

- rpm $\rightarrow$ rpm is calculated from angular velocity. Since angular velocity is the measure of speed in rad/s the relation between them is to convert seconds into minutes and radians into revolution which can be expressed as follows -

$$rpm = \frac{60}{2 \times \pi} \times angular\ velocity \tag{1}$$

- motor power $\rightarrow$ motor power is the product of the angular velocity and torque of the motor.

$$motor\ power = \omega \times \tau \tag{2}$$

where, ω is the angular velocity and τ is torque.

- energy consumption $\rightarrow$ we get the energy consumption of the motor by integrating the power of the motor.
- distance $\rightarrow$ traveled distance can be derived by integrating the feedback velocity of the vehicle.

G. Vehicle body

Vehicle body (Fig. 9) simulates mechanical forces, mass, environment, and wheels of the vehicle. To say even simply it is what we see while imagining a car. Incline angle refers to the upward and downward angle of the road from a plain expressed in radians.

Wind speed is another input given to the vehicle. It considers

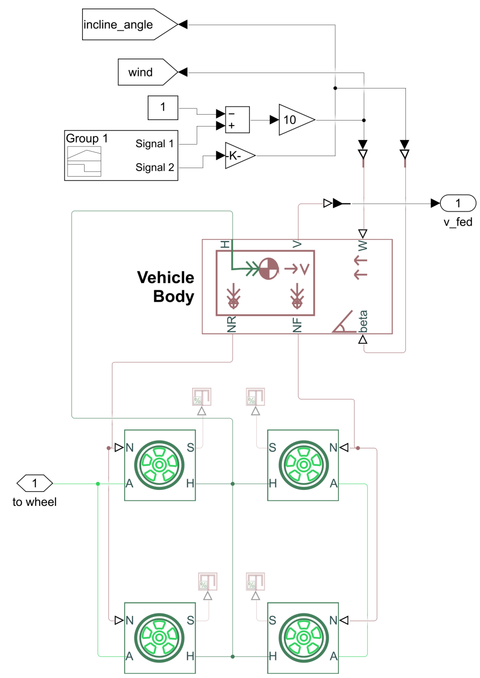

Fig. 9. Vehicle body of the FEV

the opposite wind speed to the vehicle velocity. We get the velocity feedback from this block. A vehicle body can be simulated with both 2 wheels and 4 wheels. We have taken four wheels one.

H. PMSM model

The PMSM model of the vehicle is given in Fig. 10. In this model, we have used a PMSM to simulate the same vehicle with the same input parameters. The DC vehicle model used reference velocity to control the vehicle by comparing it with the feedback velocity.

It generated the necessary acceleration and deceleration

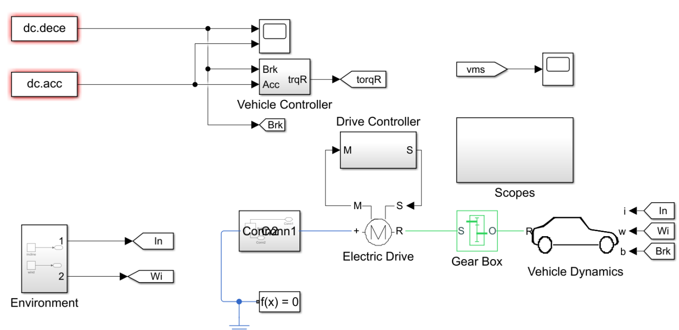

Fig. 10. Vehicle body of the FEV

command which then generated the motor current. But, in the case of the PMSM, it uses torque control. It can directly take the torque data from the DC vehicle simulation or take the acceleration deceleration data to generate the necessary torque request for the vehicle which is used as the input for the PMSM model.

III. Result and Analysis

A. DC motor simulation results

The simulation starts with the reference velocity as shown in Fig. 11. The vehicle starts at 0 m/s speed and gradually reaches about 12 m/s within 100 seconds before starting to reduce speed.

At about 170 seconds the velocity again starts to increase

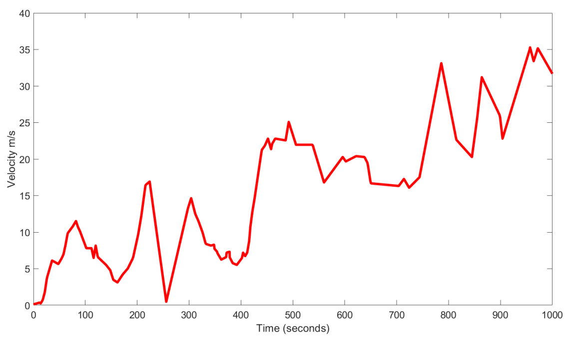

Fig. 11. Reference velocity for the vehicle

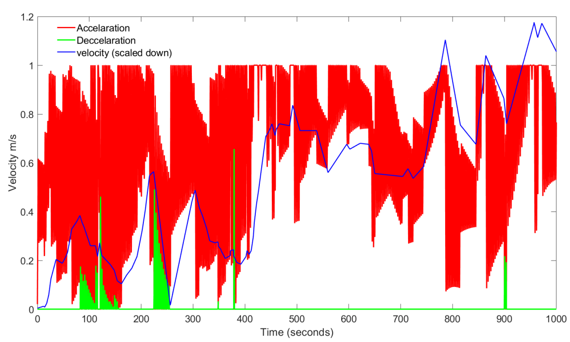

Fig. 12. Acceleration and deceleration of vehicle as per reference velocity

and reach a high amplitude of 17 m/s. Again it goes to an instant stop. After this, the velocity rises mostly and reaches a peak of about 35 m/s at 970 seconds. As per the the response of the reference velocity acceleration and deceleration acts which is shown in Fig. 12. From this figure, we see that both acceleration and deceleration act perfectly as velocity increases and decreases. We notice that deceleration happens only at the occurrence of a rapid or instant break of the vehicle. Most of the time because of the low rising and falling rate of the velocity deceleration doesn't need to act. Only in case of rapid deceleration drivetrain actives deceleration command. We see that rapid brake occurs at about 70s, 110s, 370s, 900s, and so on. So deceleration also acts at those times only.

The motor current of the vehicle is shown in Fig.13. The vehicle is controlled by the powertrain and block. It takes reference velocity and feedback velocity and finds the error between them. Then based on the error it uses the PI controller to make corrections and generates the required acceleration and deceleration signal which is fed to the PWM generator and H-Bridge. Based on these the motor is supplied with the required current to control its speed and the motor runs.

One noticeable fact is that there are heavy fluctuations both

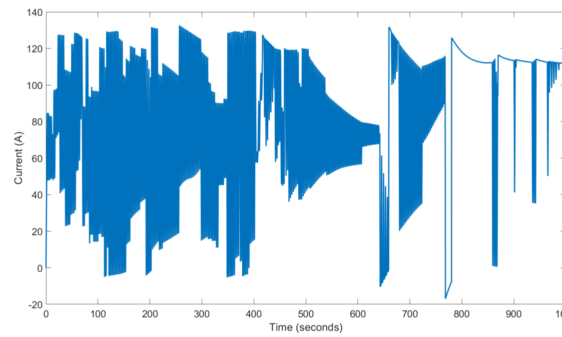

Fig. 13. Motor current

in the acceleration and motor current of the vehicle. It's mainly because of the PI controller. For the perfect control of the vehicle, we need to set the perfect tuning of the pI controller. But unfortunately in this case we didn't get any perfect P and I value for this controller. We have tried built-in PI controller tuning of MATLAB, but that didn't work because the system is not linear. So we applied and checked a lot of values and found P=1, and I=30 somehow workable. Although this tuning wasn't perfect it was workable.

Fig. 14 compares reference velocity with the actual vehicle velocity of the vehicle. We see that there are some deviations between reference and actual velocity which means that the controlling of the system works perfectly. But this deviation is the cause of the fluctuation of motor current and acceleration of the vehicle.

The mechanical outputs are depicted in Fig. 15.

The maximum torque of this vehicle is around 150 N-m and the mechanical speed of the vehicle is presented both in rad/s. The relation between angular velocity and rpm is

$$rpm = \frac{speed\ (rad/s) * 60}{2\pi} \tag{3}$$

B. PMSM simulation

3 phase AC motors are really complex to simulate and do the right control strategy. In this section, we will discuss the PMSM simulation of the same vehicle.

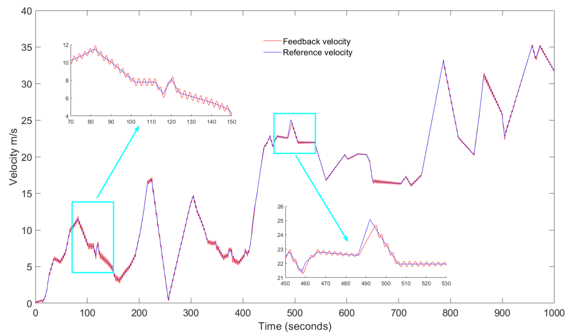

Fig. 14. Reference velocity vs actual velocity of the vehicle

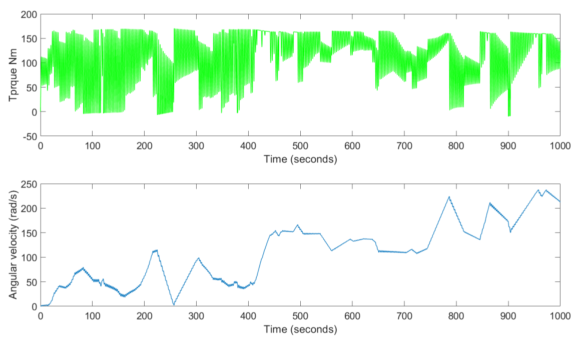

Fig. 15. Motor mechanical output

It is clearly seen from Fig.16 that the torque is relatively lower in PMSM which results in low current and power.

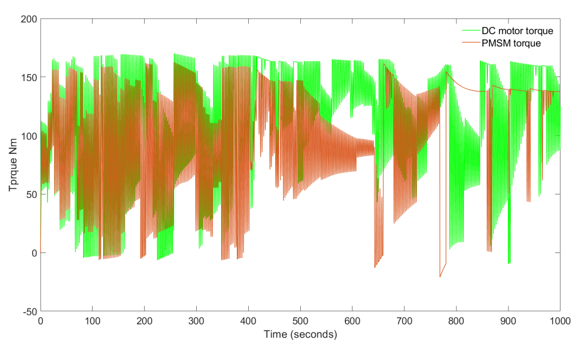

Fig. 16. Torque comparison of DC vs PMSM motors

The maximum power of the motor is 40 kW. Here we see that the maximum power the motor consumes is about 37000 w or 37 kW for DC motor and is around 30 kW for PMSM which indicates that PMSM has higher efficiency. The power of the motors is shown in Fig.17.

The total energy consumption of the DC motor is around $13.1{\times}10^6$ ws which will be around

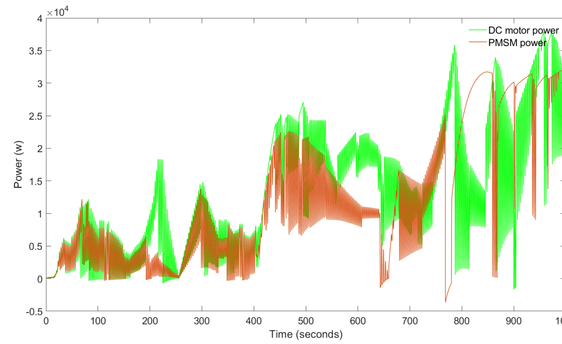

Fig. 17. Power consumption comparison of DC vs PMSM motors

$$kWh = \frac{13.1 \times 10^6 \ ws}{3600 * 1000} \tag{4}$$

$$kWh = 3.63 \tag{5}$$

and for the PMSM it is $13.1{\times}10^6$ ws means

$$kWh = \frac{11.9 \times 10^6 \ ws}{3600 * 1000} \tag{6}$$

$$kWh = 3.3 \tag{7}$$

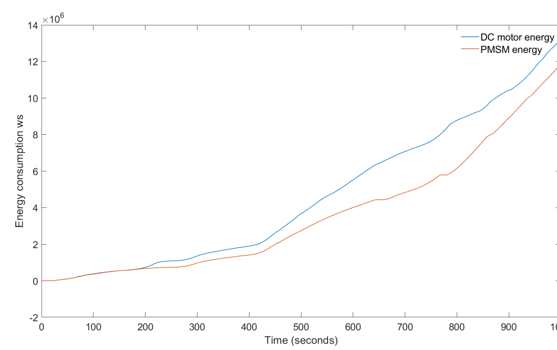

Fig. 18. Energy consumption comparison of DC vs PMSM motors

Hence it is seen that PMSM works more efficiently and consumes less power. The energy consumption scenarios of both motors are shown in Fig. 18.

The total traveled distance of the vehicle during the simulation should be identical. Distance traveled during the 1000s simulation by both motors are compared in Fig. 19. From the figure it is seen that there is a small deviation of the total distance which is completely acceptable. With two different motors, both vehicles traveled a distance of around 4500 m or 4.5 km.

In the first 600 seconds both vehicles traveled around 2000 m and in the 600 s to 1000 s both vehicles crossed 2500 m because of the high velocity during this time as seen in Fig.19.

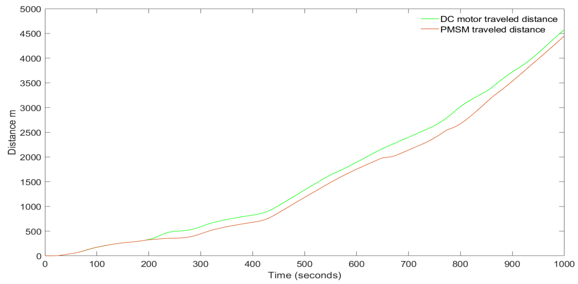

Fig. 19. Distance traveled - DC vs PMSM motors

IV. Result comparison

TABLE III. Result comparison

Parameters	DC motor	PMSM
average torque	higher	lower compared to DC motor
max torque	around 165 Nm	around 155 Nm
min torque	around - 5 Nm	around -10 Nm
rated motor power	40 kW	40 kW
max power	37 kW	32 kW
energy consumed	3.63 kWh	3.3 kWh
distance travelled	4550 m	4450 m

Based on the data presented in Table III, we can say that PMSM consumes less power, and energy and has higher efficiency. Hence it is a better choice for EVs compared to DC motors.

V. Conclusion

This article has presented a comparative study of DC and PMSM-based FCEVs, analyzing their electrical and mechanical properties. Through a MATLAB-based simulation, we compared the performance of two fuel cell vehicles, one using a DC motor and the other a PMSM motor. Our key findings indicated that the PMSM vehicle is more energy efficient, using less power while achieving the same reference velocity. However, this study has its limitations, and further research is needed to validate our results in real-world scenarios. Nevertheless, Our work provides valuable insights for the development of sustainable and efficient transport technologies, contributing to a greener future.

References

[1] T. Nguyen, J. Ward, and K. Johnson, "Well-to-wheels greenhouse gas emissions and petroleum use for mid-size light-duty vehicles," *Program Record (Offices of Bioenergy Technologies, Fuel Cell Technologies & Vehicle Technologies, US Department of Energy, Record#: 13005 (revision# 1)*, 2013.

[2] C. Tang, B. Sprecher, A. Tukker, and J. M. Mogollón, "The impact of climate policy implementation on lithium, cobalt and nickel demand: The case of the dutch automotive sector up to 2040," *Resources Policy*, vol. 74, p. 102351, 2021.

[3] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, "A review on electric vehicles: Technologies and challenges," *Smart Cities*, vol. 4, no. 1, pp. 372–404, 2021.

[4] G. Motors, "The mass-market introduction of electric-drive vehicles represents an extraordinary change for the automotive industry, offering a viable alternative to the internal combustion engine for the first time since the early 20th century.,"

[5] J. Taalbi and H. Nielsen, "The role of energy infrastructure in shaping early adoption of electric and gasoline cars," *Nature Energy*, vol. 6, no. 10, pp. 970–976, 2021.

[6] G. J. Offer, D. Howey, M. Contestabile, R. Clague, and N. Brandon, "Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system," *Energy policy*, vol. 38, no. 1, pp. 24–29, 2010.

[7] K. Sobiech-Grabka, A. Stankowska, and K. Jerzak, "Determinants of electric cars purchase intention in poland: personal attitudes v. economic arguments," *Energies*, vol. 15, no. 9, p. 3078, 2022.

[8] M. U. Mutarraf, Y. Guan, L. Xu, C.-L. Su, J. C. Vasquez, and J. M. Guerrero, "Electric cars, ships, and their charging infrastructure–a comprehensive review," *Sustainable Energy Technologies and Assessments*, vol. 52, p. 102177, 2022.

[9] Y. Van Fan, P. Jiang, J. J. Klemeš, and P. Ocłoń, "Minimum environmental footprint charging of electric vehicles: a spatiotemporal scenario analysis," *Energy Conversion and Management*, vol. 258, p. 115532, 2022.

[10] P. Ahmadi and A. Khoshnevisan, "Dynamic simulation and lifecycle assessment of hydrogen fuel cell electric vehicles considering various hydrogen production methods," *International Journal of Hydrogen Energy*, vol. 47, no. 62, pp. 26758–26769, 2022.

[11] K. E. Björnberg, M. Karlsson, M. Gilek, and S. O. Hansson, "Climate and environmental science denial: A review of the scientific literature published in 1990–2015," *Journal of Cleaner Production*, vol. 167, pp. 229–241, 2017.

[12] T. A. Huynh and M.-F. Hsieh, "Performance analysis of permanent magnet motors for electric vehicles (ev) traction considering driving cycles," *Energies*, vol. 11, no. 6, p. 1385, 2018.

[13] A. T. Swaraj Ravindra Jape, "Comparison of electric motors for electric vehicle application," *International Journal Of Research In Engineering And Technology*, vol. 06, no. 9, p. 4601, 2017.

[14] G. Luthra, "Comparison of characteristics of various motor drives currently used in electric vehicle propulsion system," *International Journal of Mechanical and Production Engineering*, vol. 5, no. 6, p. 2, 2017.

[15] T. Porselvi, M. Srihariharan, J. Ashok, and S. A. Kumar, "Selection of power rating of an electric motor for electric vehicles," *International Journal of Engineering Science and Computing IJESC*, vol. 7, no. 4, pp. 6469–6472, 2017.

[16] A. A. AbdElhafez, M. A. Aldalbehia, N. F. Aldalbehia, F. R. Alotaibi, N. A. Alotaibia, and R. S. Alotaibi, "Comparative study for machine candidates for high speed traction applications," *International Journal of Electrical Engineering*, vol. 10, no. 1, pp. 71–84, 2017.

[17] A. I. Ikram, M. S.-U. Islam, M. A. B. Zafar, M. K. R. Dept, A. Rahman, *et al.*, "Techno-economic optimization of grid-integrated hybrid storage system using ga," in *2023 1st International Conference on Innovations in High Speed Communication and Signal Processing (IHCSP)*, pp. 300–305, IEEE, 2023.

[18] B. Hollweck, M. Moullion, M. Christ, G. Kolls, and J. Wind, "Energy analysis of fuel cell electric vehicles (fcevs) under european weather conditions and various driving behaviors," *Fuel Cells*, vol. 18, no. 5, pp. 669–679, 2018.