Journal of Energy

VOLUME 72 Number 4 | 2023

journal homepage: http://journalofenergy.com/

Power Management Strategy of a PEM Fuel Cell-Battery Powered Electric Vehicle

Susanta K. Das, Jinsu Kim

Summary — **A MATLAB-Simulink based mathematical vehicle simulation model is developed in this investigation to analyze power management strategy of a proton exchange membrane (PEM) fuel cell and battery powered electric vehicle. The vehicle simulation model incorporated a real- world commercial passenger vehicle operator's drive cycle inputs and associated vehicle dynamics to determine accurate estimation of total onboard power requirements and withdrawal of power from the fuel cell and battery sources to meet the demand. The power management strategy is designed to meet the vehicle's onboard power demand based on the availability of hybrid combination of fuel cell and battery power sources. The fuel cell stack is the primary power source of the vehicle. Battery is used as a supplemental power source for meeting the vehicle's peak power demands. The fuel cell is also charging the battery with excess power produced onboard and hence controls the state-of-charge of the battery. All the important physical parameters are optimized to implement the power management strategy by considering the battery state-of-the charge, the drive torque and the vehicle drive performance. The model simulation results with optimized parameters showed that the power requirement of the electric vehicle was significantly affected by the combination of fuel cell and battery power management system as well as the vehicle operating behaviors of the end user (driver).**

Keywords — **power management, fuel cell, battery, electric vehicle, model simulation.**

I. Introduction

Serious health problems for human life and environment pollution around the world have raised lot of concerns about the usage of fossil fuels based internal combustion engine (ICE) technology in transportation and other utilityvehicles[1]. Fuel cell and battery powered electric vehicles, as an alternative of ICE vehicles, have shown the most promising among others for zero to low greenhouse gas emission, high efficiency and long operational life[2].To improve the dynamics and uninterrupted power supply issues for the smooth operation of electric vehicles, a hybridization of fuel cell system (FCS) with an energy storage device such as lithium-ion battery pack can be a beneficial system. Hybridization is also helpful to achieve better fuel economy and performance by the optimization of fuel-cell and battery power sharing system. Through a power management strategy (PMS) based on the vehicle operating behaviors of the end users i.e. drivers, the optimization of this hybrid system is accomplished by distributing the load power between the fuel cell stack and batterypack. The design of such a PMS should be made by ensuring that each energy source operates within its limits to achieve an optimal fuel economy. The primary objectives of this investigation are to evaluate a power management strategy through implementation in a fuel cell and battery electric vehicle simulation model.

Even though fuel cell and battery powered electric vehicles (FCBPEVs) have not yet entered into the nationwide commercialization phase in large scale, fuel cell and battery powered electric vehicles have a great potential to be the most efficient environment friendly vehicles in the transition of the transportation sector [3]. FCBPEVs are characterized where a fuel cell stack acts as the main power source and a battery as an auxiliary energy storage device (AESD) to supplement the electric vehicle's peak powerdemandas needed [4]. Instead of a full fuel cell stack based powertrains, to form a hybrid powertrain mode by adding anAESD is advantageous: (1) since initially the FCS requires a little bit long start-up times due its slow electro-kinetics; hence an AESD is needed to starting up and also to improve the responsiveness of the peakpower demand during vehicle acceleration; (2) in the hybrid fuel cell and battery system, the fuel cell stack needs to be sized according to the cruising demand only since the AESD helps meet the peak power demands; (3) the AESD is also significantly improve the fuel economy by restricting the FCS to operate at a high-efficiency operating point and also leave the option open for the possibility of adding a regenerative braking system. For electric vehicles application, the hybrid fuel cell and battery system are required to achieve a minimum operational life time of 5000h [5] in orderto be comparable with the current internal combustion engine (ICE) based automotive powertrains.

Because of differences in their characteristics, multiple powersources involved in the hybrid powertrain affect electric vehicle performance considerably [6-7]. In the FCS, load changing characteristic leads to many degradations such as membrane dehydration, flooding of the porous electrodes' media and gas starvation causes the loss in the catalyst layer [8]. Hence, to increase the FCS lifetime, the FCS load dynamics need to be adjusted accordingly. On the other hand, battery lifetime depends on the depth-of-discharge as well as the charge-discharge rate of the battery. The discharge capacity of the battery usually decreases due to increase in the internal resistance as the battery aging [9]. Also, the battery operating conditions contribute significantly in cycle life of the battery.

Hence, to achieve optimal performanceand maximum fuel economy for FCBPEVs, power management strategy must be determined to accurately sizing the fuel cell stack and battery pack. Inthis study, we analyze the powermanagement strategy of a fuel

(Corresponding author: Susanta K. Das).

Susanta K. Das is with the Mechanical Engineering Department, Kettering University, Flint, MI 48504 USA (e-mail: sdas@kettering.edu).

Jinsu Kim is with the Mechanical Engineering Department, Kettering University, Flint, MI 48504 USA (e-mail: kim3045@kettering.edu).

Susanta K. Das, Jinsu Kim, Power Management Strategy of a PEM Fuel Cell-Battery Powered Electric Vehicle, Journal of Energy, vol. 72 Number 4 (2023), 3–8
https://doi.org/10.37798/2023724499

cell-battery powered electric vehicle by employing MATLAB and Simulink model. A mathematical FCBPEV simulation model was designed and using MATLAB and Simulink we optimized various physical model parameters to understand the power management strategy.

II. Simulation Model Description and methods

In this study, a mathematical FCBPEV simulation model is designed by considering the actual real-world vehicleo peration point of view. Figure 1 shows an overall vehicle simulation model diagram. The complete vehicle simulation model is comprised of six parts: drive cycle source, driver block,energy management system (EMS) block, electrical subsystem block, driveline block, and vehicle dynamics block. Using the MATLAB and Simulink software package [10], major vehicle components and control strategies were designed in each individual subsystem block and connected to each other to form a complete vehicle simulation model. The mathematical model equations used for the fuel cell stack in this study are given in our earlier publication [11] and the battery pack model equations provided in the publications [12-13] were used in the present Matlab-Simulink model simulation study.

The simulation model starts with a driver block that determines the acceleration required to achieve desired vehicle speed from the drive cycle source and provides it to the EMS block in the form of pedal position. The EMS block then calculates the reference torque of the electric motor and the reference current of the fuel cell based on an implemented control strategy [14]. With the reference torque values, the hybrid power train in the electrical subsystem block determines the actual motor torque and calculates required power based on the reference current load from the fuel cell stack. The vehicle's tractive force is then determined through the driveline block and the actual vehicle speed is calculated from the relationship between the road load force and the tractive force in the vehicle dynamics block.

The vehicle simulation model was optimized by implementing the power management mechanism and different operating conditions to understand the effect of various parameters on the overall vehicle performance. The designed vehicle simulation model was simulated by employing two types of driving cycles that are commonly used in the United States (U. S.) - the Urban Dynamometer Driving Schedule (UDDS) and the Highway Fuel Economy Test (HWFET) Driving Schedule to understand the power sharing mechanism of a FCBPEV. These two driving schedules, UDDS and HWFET, are parts of various drive cycles established by the U.S. Environmental ProtectionAgency(EPA) [15]. The U.S. EPA has published fuel economy test data of millions of new vehicles sold in the U. S. since late 1970s. UDDS describes a standard city driving pattern represented by frequent stops and go's. Whereas, unlike the city test, HWFET keeps the vehicle speed consistently in the range of 45 to 70 mph with the minimum usage of brakes.

A fuel cell-battery electric vehicle usually utilizes a fuelcell system as the main power source and a battery pack as the auxiliary power

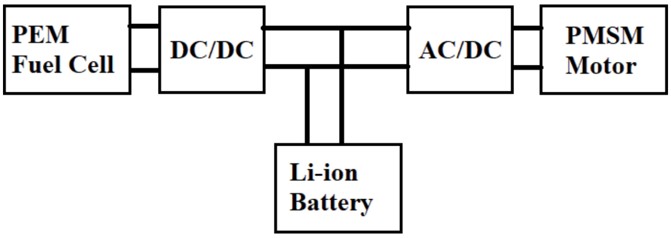


Fig. 2. EMS Block and electrical subsystem block for a fuel cell-battery hybrid powertrain system

source because the fuel cell alone may not be enough to satisfy all dynamic load demands in real-time vehicular applications [16]. Thelithium-ion batterypack in the model acts as an auxiliary power source to assistthe PEM fuel cell stack power supply as well as it also acts as an energy storage system to store produced surplus fuel cell energy or even restore the energy from regenerative braking as every time vehicle stops and start, it turns kinetic energy into electricity that is used to charge the battery and improve the system efficiency. Since the fuel cell stack voltage is higher than the dc bus voltage, a step-down DC/DC converter (or sometimes called a buck converter) was connected to the fuel cellsystem. One of the main challenges for the development of a hybrid electric vehicle is the management of multiple power sources and converters [17-18]. For a vehicle with hybrid power train, therefore, a power management strategy is required to accurately distribute the power between different power sources.Theenergymanagementsystem(EMS) blockcontains the power management strategy as well as the drive torque/power calculation block. In this study, The Energy Management Subsystem (EMS) block and the Electrical Subsystemblock were adapted from MATLAB/Simulink Sim-Power Systems library [10]. A diagram of the fuel cell-battery hybrid power train implemented in the EMSblock and electrical subsystem block is provided in Fig. 2.

In this study, the EMS and electrical subsystem shown in Fig. 2 consists of [10, 14]:

- A 100-kW permanent magnet synchronous motor (PMSM) with maximum torque of 256 N.m and maximum speed of 12,500 rpm.
- A 25kW, 288Vdc ,86.8Ah lithium-ion battery pack.
- A 100kW, 288Vdc proton exchange membrane(PEM) fuel cell stack.
- A step-down DC/DC converter.

It is noted that, in this study, an electric motor has been treated as the power source (i.e. heat engine) that is the closest to the ideal power plant because of the constant power output over the high-speed range and the constant torque output over the low-speed range [1]. Unlike the conventional gasoline engine, the electric motor used in the fuel cell-battery electric vehicle can produce torque at zero speed and efficiency of power plant is less dependent on

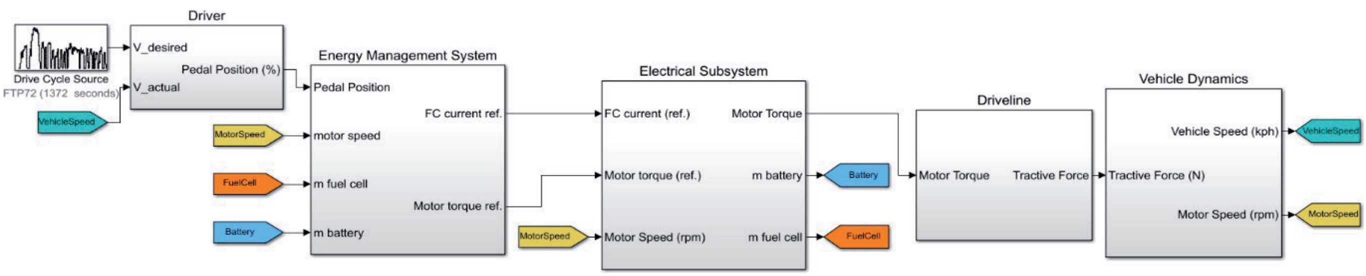


Fig. 1. MatLab-Simulink based fuel cell-battery powered electric vehicle (FCBPEV) simulation model

Susanta K. Das, Jinsu Kim, Power Management Strategy of a PEM Fuel Cell-Battery Powered Electric Vehicle, Journal of Energy, vol. 72 Number 4 (2023), 3–8
https://doi.org/10.37798/2023724499

its operating points. Due to this ideal torque-speed profile, a single-gear transmission is commonly used for the vehicle with the electric motor.

The battery management system shown in Fig.2 determines the battery State of Charge (SOC) limit and the battery power limit as well as the battery recharged power based on the measured voltage and SOC. The power management system then determines the reference motor torque and the reference fuel cell current based on the battery recharge power and the batterylimits calculated from the battery management system.

The model simulation starts with the torque calculation block, shown in Fig. 1, that calculates the drive torque and drive power using the pedal position and motor torque-speed relationship. In order to convert the motor speed to motor torque, peak performance curve of the motor was generated using the maximum torque, speed, and power demand values of the motor. The reference fuel cell power is calculated by adding the battery recharge power to drive power. The drive power is described as a subtraction in the block (see Fig. 1) because the recharge power is usually expressed as negative value by convention. The reference fuel cell stack current is then determined using the polarization curve of the fuel cell stack. The reference Battery Power block determines the behavior of the battery using the reference fuel cell power, measured fuel cell power, battery recharge power, and the battery power limit. The battery power block commands the battery to help the fuel cell when the fuel cell alone cannot provide the required drive power to the motor. Since the fuel cell system cannot react quickly, due to its long response time at pre-start, the switch block is used to ensure that the battery power kicks in while the fuel cell system heats up at the time of start of the vehicle.

The driveline block, shown in Fig. 1, converts the motor torque produced by the electric motor considering the tractive effort on the wheels. The torque of the power plant such as an engine or an electric motor is, in general, transmitted to the wheels through a clutch in manual transmission or a torque converter in automatic transmission, gearbox, final drive, differential, and drive shaft. The driveline block is also considered the traction limit. When the tractive resistance of a vehicle exceeds the limit of the maximum tractive force due to the friction between the tire and the ground, the vehicle cannot go forward and the wheels will spin on the ground. For the accuracy of the simulation, therefore, the tractive limit due to the friction has been taken into consideration. The vehicle dynamics block calculates the vehicle speed using the tractive force estimated from the vehicle dynamics block, see Fig. 1. Using the tractive force, the power required from the motor to propel the vehicle moving forward at a specific speed can be determined.III.

III. Results and Discussions

To verify the power management strategy embodied in the Energy Management System (EMS) block, first, the vehicle model was simulated with a series of step input signals to verify the pedal position at different scenarios. The baseline vehicle model is then validated by running the simulation with the two drive cycles (UDDS and HWFET) and analyses the results in terms of power sharing mechanism with a certain amount of vehicle driving distance.

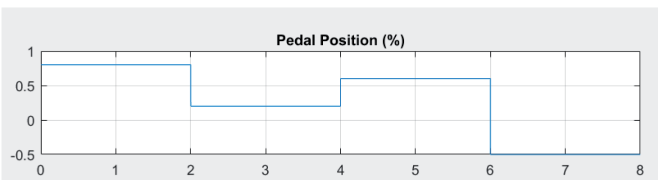


Fig. 3. Pedal position step input signal validation

In order to understand the power sharing mechanism, the vehicle model is simulated with a series of step input signals, after verification of pedal position, that describes different modes of operation such as fast acceleration, gentle acceleration, and braking [14] to verify that the power management strategy implemented in the EMS block properly controls the power sources at different scenarios. Fig. 3 represent a series of four step input signal for power control strategy validation describes the following operational management strategy implemented in the EMS block properly controls the power sources at different scenarios. Fig. 3 represent a series of four step input signal for power control strategy validation describes the following operational behaviors: (a) the accelerator pedal is pushed to 80% (fast acceleration), (b) the accelerator pedal is released to 20% (gentle acceleration), (c) the accelerator pedal is pushed again to 60% (fast acceleration), (d) the brake pedal is pushed to 50% (deceleration).

For the baseline vehicle model, the values of vehicle dynamics and driveline parameters have been estimated based on the generalized use of the vehicle as shown in Table I.

TABLE I
Vehicle Dynamics Parameters of the Baseline Vehicle.

Parameter	**Value**
Vehicle mass, m	1800 kg
Width of vehicle, W	1.85m
Height of vehicle, H	1.50m
weight distribution, $i_{WD,f}/i_{WD,r}$	0.52/0.48
Tire dynamic radius, r_d	0.315m
Single gearset ratio, $i_g i_0$	8:1
Driveline efficiency, η_t	0.90
Friction coefficient (dryroads), μ	0.75
Tire dynamic radius, r_d	0.315m
Drag coefficient, C_d	0.3
Rolling resistance coefficient, f_{rr}	0.015
Incline angle, θ	0 (level ground)
Mass factor, k_m	1.05

After validation of pedal position with the step input signal, as shown in Fig. 3, the driver block and drive cycle block from the vehicle simulation model, as shown in Fig. 1, were replaced with the pedal position signal block and hence the signal input was regarded as the pedal position and directly connected to the EMS block [14]. Hence, it makes the vehicle simulation mode more robust and forged coupling of vehicle speed, battery SOC, and power distribution between battery and fuel cell depending on the pedal position input.

Susanta K. Das, Jinsu Kim, Power Management Strategy of a PEM Fuel Cell-Battery Powered Electric Vehicle, Journal of Energy, vol. 72 Number 4 (2023), 3–8
https://doi.org/10.37798/2023724499

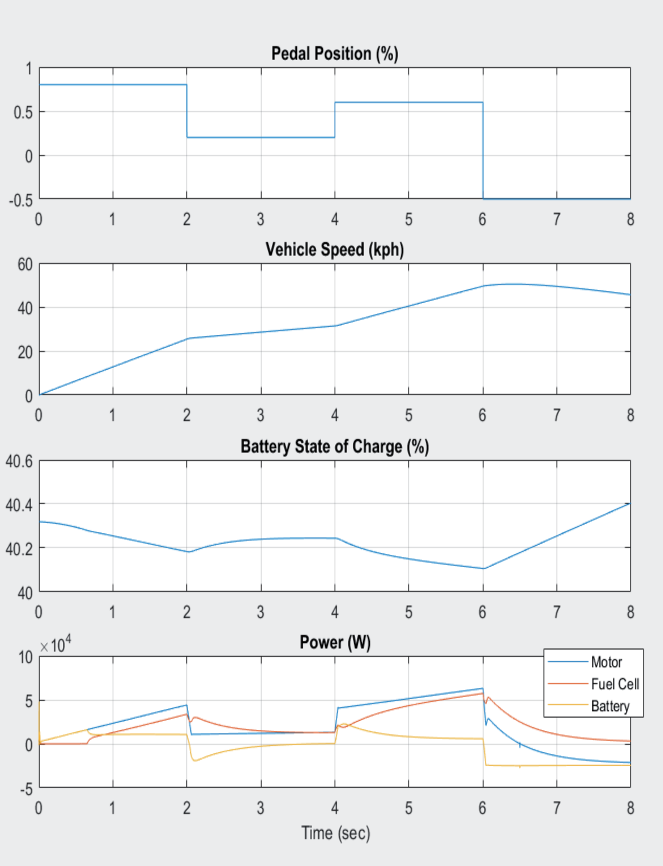
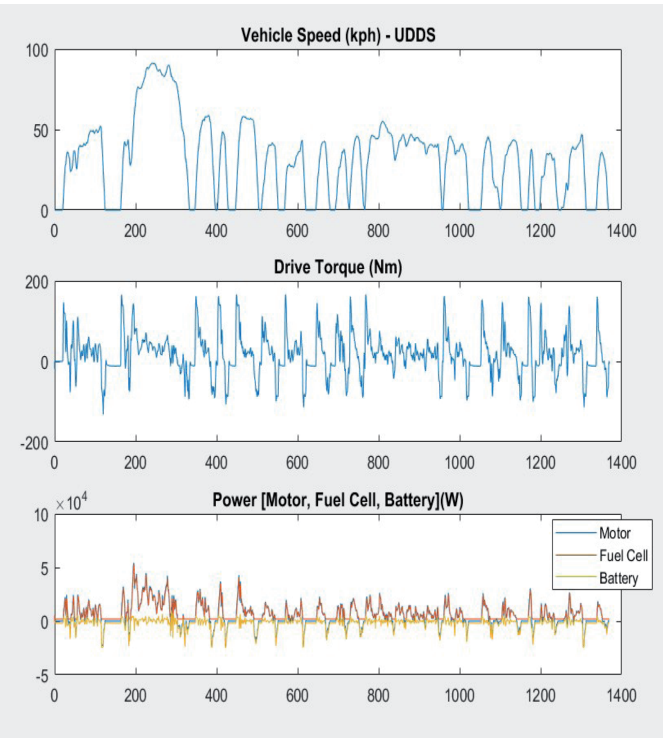


Fig. 4. Vehicle speed, battery SOC and power distribution curves of fuel cell and battery based on the pedal position

Fig. 4 shows the vehicle model simulation results of vehicle speed, battery SOC, and power distribution curves of battery and fuel cell depending on the corresponding pedal position input. The pedal position signal consists of a series of four step inputs: 80% at 0 s, 20% at 2 s, 60% at 4 s, and -50% at 6s. the negative accelerator input is regarded as the brake pedal position. From Fig. 4, it can be seen that at time t = 0, the vehicle is at idle (stopped) position and the driver pushes the accelerator pedal to 80% (fast acceleration). At this situation, the battery alone provides the power to the motor until the fuel cell starts to provide the power. The vehicle speed steadily goes up and the battery power is also depleted rapidly as can be seen from Fig. 4. At 0.7 seconds, the fuel cell starts to provide power to the motor as a main power source while the battery continues to provide power as an auxiliary power source to meet the motor power demands. At 2 seconds, the accelerator pedal is released to 20% (gentle acceleration). Now, the fuel cell solely provides the power and battery power goes to zero. As the accelerator pedal is pushed hard to 60% (fast acceleration) at 4 seconds, the battery kicks in again and start to help the fuel cell stack to realize the power demand. Then the driver pushes the brake pedal to 50% at 6 seconds. The motor acts as a generator now and restore the fuel cell excess energy into the battery by charging it through regenerative braking system. The battery SOC starts to increase as the battery energy is restored. It can be concluded from the results presented in Fig. 4 that the power was successfully distributed and shared between the battery and the fuel cell as initially intended by the energy management system (EMS) block. Hence, the power management strategy applied in the EMS block was validated and found to be worked properly.

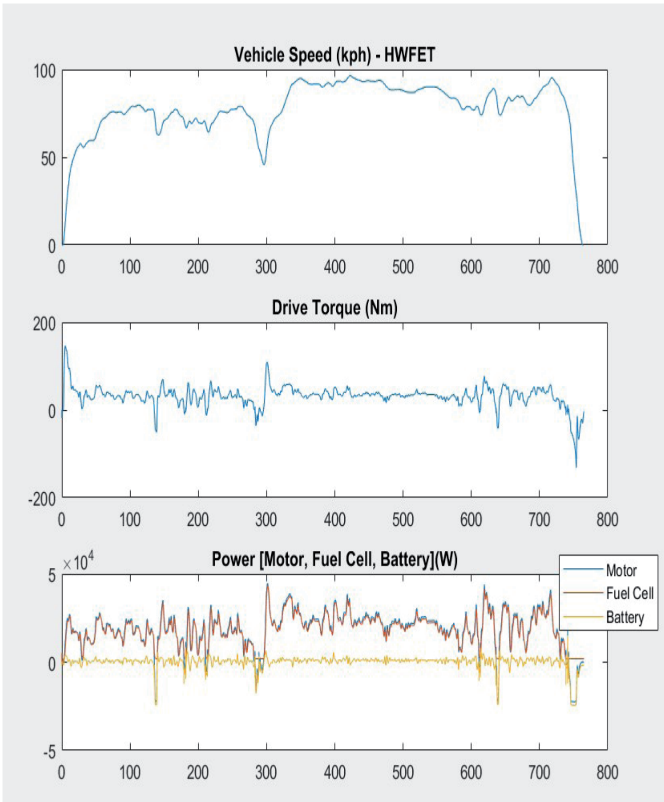
The vehicle simulation model was run with UDDS (city) schedules for 1400 seconds and HWFET (highway) driving schedules for 800 seconds to understand the power sharing mechanism between power providing sources - fuel cell and battery during the city driving and highway driving conditions.

Fig. 5 represents the vehicle speed, drive torque and power sharing curves during the city driving using city driving schedule. From Fig. 5, it can be found that the maximum drive torque is measured as around 180 Nm during the city driving test. Since the torque was maintained below the maximum torque of the motor



Time(sec)

Fig. 5. Vehicle speed, drive torque and power distribution curves of fuel cell and battery on City driving test



Time(sec)

Fig. 6. Vehicle speed, drive torque and power distribution curves of fuel cell and battery on Highway driving test

Susanta K. Das, Jinsu Kim, Power Management Strategy of a PEM Fuel Cell-Battery Powered Electric Vehicle, Journal of Energy, vol. 72 Number 4 (2023), 3–8
https://doi.org/10.37798/2023724499

of 256 Nm during the whole cycle, the fuel cell only provided the required power to the motor for most of the time and the battery mainly acts as an energy storage during this test. As can be seen from Fig. 5, the negative torque profile appears a lot because of frequent stops in the city test. This leads to a frequent battery charging due to regenerative braking. The maximum fuel cell power was measured as 52 kW while the maximum battery power was only measured as 3 kW. From Fig. 5, it can also be seen that since the city driving is limited mostly within 50 km/h, the fuel cell power source was provided the required power most of the times and the battery storage the excess power produced by the fuel cell as indicated by the negative spike of power curves for the battery during the city driving. For an instance of high vehicle speed during the city driving between 200-350 seconds, as shown in Fig. 5, it can be seen that the battery power supplemented the power to the fuel cell power in order to meet the additional power needed for high speed city driving. This can be clearly seen from Fig. 5 as the negative power spikes diminished for battery power curve during the high-speed city driving between 200-350 seconds. It clearly demonstrated the power sharing and power saving mechanism during the city driving as the power management strategy incorporated nicely in the developed vehicle simulation model in this study.

Fig. 6 represents the vehicle speed, drive torque and power sharing curves during the highway driving using the highway driving schedule. From Fig. 6, it can be seen that the maximum drive torque was measured as around 150 Nm during the highway driving test. Similar to the city driving test, the torque stayed below the maximum torque of the motor of 256 Nm during the entire highway driving cycle. From Fig. 6, it can be seen that the fuel cell power source was mostly provided the power to the motor and the battery power supplemented to meet the peak power demand only and the battery was acted as an energy storage very less frequently as very few negative power spikes displayed by the battery power curves during the highway driving test. The maximum fuel cell power was measured as 45 kW while the maximum battery power was measured as 2.3 kW. From Fig. 6, it is also seen that there are very few negative torque spike curves due to the fact that the vehicle is driven most of the times above the speed of 50km/h and less frequent stops because of no traffic light at the highway. From Fig. 6, it was found that when the vehicle speed was very high, for instance, highway driving time between 300-600 seconds, the required motor power was supplied by the fuel cell system and the battery as can be seen from Fig. 6, During this time, 300-600 seconds, the battery power curves show almost no negative spike instead it shows frequent small positive spikes. It indicated that during the high vehicle speed at the highway driving, the battery mostly supplemented the power with fuel cell power to fulfill the peak power demand of motor to maintain the same high speed during 300-600 seconds as can be seen from Fig. 6, It also found that the vehicle's drive torques were almost remained the same during the highway driving periods 300-600 seconds. Overall, from Fig. 6, it can be seen that the vehicle speed, drive torque and power sharing between the fuel cell and battery power sources were correlated excellently as expected in the developed vehicle simulation model.

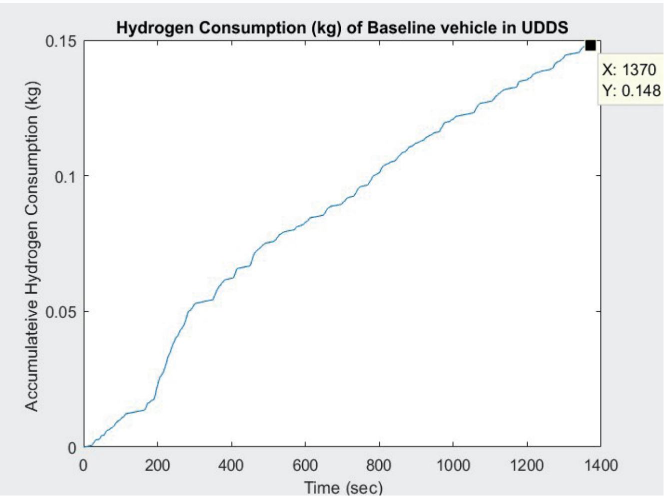


Fig. 7. Amount of hydrogen consumption during City driving test of fuel cell–battery electric vehicle

Fig. 7 represents the amount of hydrogen consumption during the city driving test. The hydrogen consumption amount is calculated using the developed Mathlab-Simulink model of fuel cell-battery electric vehicle while used the city driving schedule. In the model, the hydrogen consumption rate of the fuel cell stack was calculated using the equation (1) give as [2]:

$$Hydrogen\ consumption\ \text{rate} = \frac{i_{fc}RTN}{2FP_{fuel}x\%} \tag{1}$$

where i_{fc} is the fuel cell current, R is the ideal gas constant $\left(8.3145\ \frac{J}{mol\ K}\right)$, T is the operating temperature, P_{fuel} is the absolute supply pressure of fuel, N is the number of cells, F is the Faraday's constant $\left(96{,}485\ \frac{A\ s}{mol}\right)$, x is the hydrogen composition in the fuel.

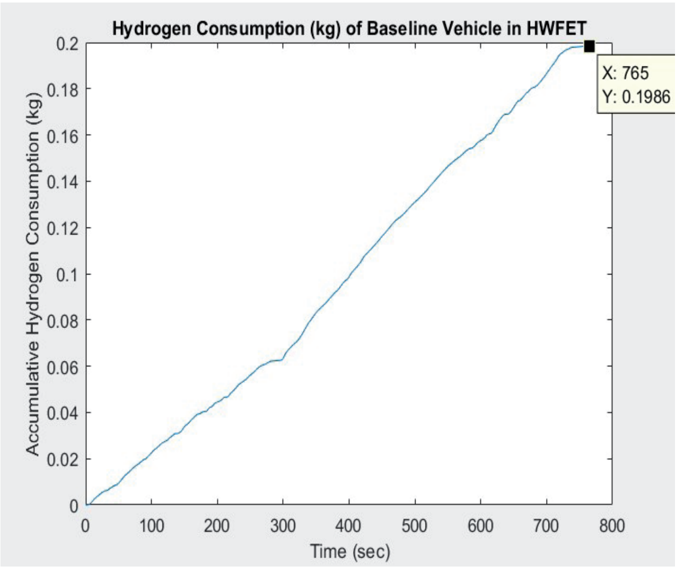


Fig.8. Amountofhydrogenconsumptionduring Highwaydriving test of fuel cell–batteryelectric vehicle

From Fig. 7, it can be seen that the total hydrogen consumption during the city driving cycle was about 0.148 kg during the total city driving time of 1370 seconds i.e. around 23 minutes. The average city driving speed was calculated at around 32 mile per hour. The total distance travel with the city driving schedule was around 12 miles and hence the city fuel economy rating was calculated as around 81 miles per kilogram of hydrogen used.

Fig. 8 shows the amount of hydrogen consumption during the Highway driving test of fuel cell-battery electric vehicle. The hydrogen consumption amount was calculated using equation (1) and employing the Matlab-Simulink model parameter values while using the Highway driving schedule. From Fig. 8, it is observed that the total hydrogen consumption during the total 765 seconds i.e. about 13 minutes of highway driving test using the Highway driving schedule was about 0.1986 kg. Total distance travel during the Highway driving schedule test was about 14 miles with around 65 miles per hour vehicle speed. Based on the collected data using the Highway driving schedule and driving test, the highway fuel economy rating was calculated as around 71 miles per kilogram of hydrogen used.

Comparing Figs. 7 and 8, it can be seen that the fuel economy rating is higher at the city driving than highway driving of the fuel cell-battery electric vehicle. The results show the usual trend for an electric vehicle compared to an internal combustion engine-based gasoline/diesel vehicle. Since the fuel cell-battery electric vehicle utilize regenerative braking system to recover lost energy due to frequent braking for traffic stops during city driving and hence the fuel economy rating is higher at city driving compared to highway driving due to no to less traffic stop on the highway driving. The conventional gasoline vehicles have higher highway fuel economy ratings than the city ratings because of large kinetic energy loss due to frequent braking for traffic stops during city driving. Based on the results presented in this study, it can be seen that unlike the conventional vehicles, fuel cell-battery electric vehicles have higher city fuel economy rating than the highway rating because of the braking energy is recovered through regenerative braking system.

IV. Conclusions

A Matlab-Simulink based complete vehicle simulation model of a fuel cell-battery powered electric vehicle was designed and simulated to understand the power management strategy of fuel cell and battery power supply sources. The developed vehicle simulation model was tested with two U.S. standard driving cycles such as city driving cycle (UDDS) and highway driving cycle (HWFET) to understand the underlying physics of fuel cell-battery electric vehicle's power management system. In the model simulation, it was assumed that the rechargeable battery pack was maintained appropriately to prevent over-heating and no loss of storage capacity degradation. It is also assumed that the water management system was put in place for the fuel cell stack to maintain the humidity inside the fuel cell at an appropriate level to prevent membrane dehydration. The results obatined in this study showed that the power management strategy implemented in the vehicle simulation model successfully distributed the power between the fuel cell and battery in both the city driving and highway driving conditions. The simulation results also showed that there is a strong correlation among vehicle speed, driving torque and power distribution mechanism in the fuel cell and battery powered electric vehicle. The results clearly showed that, unlike the conventional vehicles, fuel cell-battery electric vehicles have higher city fuel economy rating than the highway rating because of the lost braking energy for frequent traffic stops is recovered through regenerative braking system. The model simulation results provided an important insight and improved understanding in power management mechanism of a fuel cell and battery power electric vehicle. The knowledge gained in this investigation will definitely be useful for further exploration in a future study.

Acknowledgment

The author, Jinsu Kim, thanks the sponsored research office of Kettering University for providing a graduate research assistantship through an external research grant funding during accomplishing this research work.

References

[1] M. Ehsani, Y. Gao, S. E. Say and A. Emadi, "Modern electric, hybrid electric, and fuel cell vehicles: Fundamentals, theory, anddesign.,"CRC Press, 2005.

[2] F. Barbir, "PEM fuel cells: Theory and practice.,"Academic Press, 2013.

[3] S. Onori, L. Serrao and G. Rizzoni,"Hybrid electric vehicles: Energy management strategies," London: Springer, 2016.

[4] S. K Das and J. Kim,''Evaluation of power sharing mechanism of a PEMfuel cell-battery powered electric vehicle", Proc. 2023 4th International conference on Clean and Green Engineering (CCGE), held in Ankara,Turkey, August 26-28, IEEE Press, ISBN 979-8-3503-3978-8, p. 112- 117, 2023.

[5] J. Kim, "Power supply management of a fuel cell-battery hybrid electric vehicle, " M.Sc. thesis submitted to Kettering University, 2020.

[6] Y. Manoharan, S. E. Hosseini, B. Butler, H. Alzhahrani, B. T. Fou Senior, T. Ashuri and J. Krohn, "Hydrogen Fuel Cell Vehicles; Current Status and Future Prospect," Appl. Sci., vol. 9, pp. 2296-2314, 2019.

[7] S. E. Hosseini and B. Butler, "An overview of development and challenges in hydrogen powered vehicles," Int. J. Green Energy, vol. 17(1), pp.13–37,2020.

[8] J. Larminie and A. Dicks, "*Fuel cell systems explained*.," Chichester,West Sussex: J. Wiley, 2003.

[9] A. A. Kebede, T. Coosemans, M. Messagie, T. Jemal, H. A. Behabtu, J. V. Mierloand M. Berecibar, "Techno-economic analysis of lithium-ion and lead-acid batteries in stationary energy storage application," J. EnergyStorage, vol. 40, pp.102748-102767, 2021.

[10] MATLAB and Simulink R2023a, The MathWorks, Inc., Natick, Massachusetts, United States.

[11] S. K. Das and H. A. Gibson, "Threedimensional multi-physics modeling and simulation for assessment of mass transport impact on the performance of a high temperature polymer electrolyte membrane fuelcell", J. Power Sources, vol. 499, pp. 229844, 2021.

[12] D. Linden and T. B. Reddy edited, "Handbook of Batteries", 3rd Ed.,McGraw-Hill, New York, 2002.

[13] S. K. Das, A. Sarkar and K. J. Berry, "Experimental Performance Evaluation of a Hyper-Branched Polymer Electrolyte for Rechargeable Li-Air Batteries", J Front. Energy Res., vol. 8, pp. 00075, 2020. doi:10.3389/fenrg.2020.00075.

[14] S.N. Motapon, O. Tremblay, and L-A. Dessaint,"Development of a generic fuel cell model: application to a fuel cell vehicle simulation.,"Int. J. Power El ectronics,*vol.*4(6),pp.505-522,2012.

[15] Data on Cars used for Testing Fuel Economy. (n.d.). U. S. Environmental Protection Agency. Retreived fromhttps://www.epa.gov/compliance-and-fuel-economy-data/data-cars-used-testing-fuel-economy

[16] H. Yang, Y. J. Han, J. Yu, S. Kim, S. Lee, G. Kimand C. Lee,"Exploring future promising technologies in hydrogen fuel cell transportation," J. Sustainability, vol. 14, pp. 917-936, 2022.

[17] S. N. Motapon, L.-A. Dessaint, and K. Al-Haddad,"A comparative study of energy management schemes for a fuel-cell hybrid emergency powersystem of More-Electric aircraft," IEEE Trans. Ind. Electronics, vol.61(3), pp. 1320-1334, 2014.

[18] S. N. Motapon, O. Tremblay and L.-A. Dessaint, "A generic fuel cellmodel for the simulation of fuel cell power systems," Power & EnergySociety General Meeting, pp. 1-8, 2009.

Susanta K. Das, Jinsu Kim, Power Management Strategy of a PEM Fuel Cell-Battery Powered Electric Vehicle, Journal of Energy, vol. 72 Number 4 (2023), 3–8
https://doi.org/10.37798/2023724499