BIS ENERGY AND ENGINEERING
Volume 1 2024 | DOI: 10.31603/biseeng.31
5th Borobudur International Symposium on Science and Technology (BIS-STE) 2023
UNIMMA PRESS
Universitas Muhammadiyah Magelang

Modeling of an electrically driven PEM fuel cell bus

H Solmaz[1], T A Arslan[2] and T Kocakulak[3*]

[1] Department of Automotive Engineering, Gazi University, Turkey
[2] Department of Automotive Engineering, Afyon Kocatepe University, Turkey
[3] Vocational High School of Technical Sciences, Burdur Mehmet Akif Ersoy University, Turkey
*Corresponding author email: tkocakulak@mehmetakif.edu.tr

Abstract

When the literature and the goals of the leading companies in the automotive industry are examined, it is seen that the transition to electrification and renewable energy sources in the automotive industry is inevitable. It is known that the ideal renewable energy source for mobile systems is hydrogen. The most efficient conversion of hydrogen into electrical energy occurs with PEM fuel cells. Energy efficiency and environmental pollution factors are of great importance in transportation. The use of public transportation plays a significant role in improving these factors. In this study, the effects of using PEM fuel cells on energy efficiency and hydrogen consumption in buses used in urban public transportation were examined. Models of the power, linear vehicle, control, and energy systems of the fuel cell bus were created in the MATLAB Simulink environment. In the power system model, the electric motor characteristic map is used. Vehicle speed control is provided by PID controls. In the vehicle linear model, a model of the resistance forces acting on the vehicle was created. The energy system has a fuel cell system and battery pack model. NEDC and ECE-R15 drive cycles were used to evaluate the performance parameters of the bus. With the created model, the effects of changes in parameters such as total vehicle weight, rolling resistance coefficient, gear ratio, and regenerative braking efficiency on vehicle acceleration performance and hydrogen fuel consumption were examined.

Keywords

PEM fuel cell bus, Electrically energy, Automotive industry

Published:
October 20, 2024

Selection and Peer-review under the responsibility of the 5th BIS-STE 2023 Committee

Introduction

Due to the increase in the world population and economic developments, the energy spent on transportation is also increasing [1]. The widespread use of internal combustion engines in these areas also plays a vital role in the demand for fossil fuels. Emissions from conventional energy production are one of the leading causes of environmental pollution and global warming [2]. According to the International Energy Agency (IEA), the largest source of CO2 emissions globally is the transportation sector, with a share of 28% [3]. Increasing air pollution and climate change significantly threaten the health of all living things on Earth [4]. In addition, dwindling fossil fuel resources and growing demand are increasing energy costs [5]. According to the U.S. Energy Information Administration, crude oil prices increased by 50.6% from November 2018 to November 2023 [6]. These adverse conditions force manufacturers and researchers to improve internal combustion engines and emission control methods, increase electrification in transportation, and expand alternative renewable energy sources. With the 2015 United Nations Climate Change Conference [7] and the First Climate Act [8], the goals of limiting global warming to below 2°C and achieving zero greenhouse gas emissions by 2050 have brought the concepts of sustainable and green transportation back to the forefront. Although the amount of pollutant emissions from internal combustion engines produced in recent years is considerably lower than in the past, these engines with advanced emission control systems are still not environmentally friendly enough [9]. On the other hand, battery electric vehicles do not produce emissions during use, but the grid electricity that charges these vehicles is obtained mainly from fossil-based power plants [10]. In addition, the problems of battery electric vehicles, such as long charging time, short range, inadequate grid infrastructure, and fire safety, have not yet been fully resolved [11,12]. Industry stakeholders are focusing on the active use of zero-carbon hydrogen energy in vehicles to solve these problems of internal combustion engines and battery electric vehicles.

As an alternative energy source, hydrogen is a viable short-term solution to maximize performance and range while minimizing fuel consumption and pollutant emissions [13]. According to another study by the International Energy Agency (IEA), the amount of electrical energy produced from hydrogen energy increased by 103.3% from 1990 to 2020, and hydrogen is a share of 16.6% among all sources in 2020 [14]. This situation shows that hydrogen, critically important in the energy sector in the coming years, can be used more widely and cost-effectively for electricity generation [15]. Today, proton exchange membrane (PEM) fuel cell vehicles, which convert hydrogen energy into electrical energy to reduce dependence on fossil fuels, are becoming a solid alternative to internal combustion engine vehicles and battery electric vehicles [16,17]. PEM fuel cells are recognized as the most practical fuel cell application for vehicles due to their low operating temperature and pressure [13]. In PEM fuel cell electric vehicles, electricity is generated due to the reaction between hydrogen and oxygen, and only non-polluting pure water and heat are released as waste [18]. This is promising for greenhouse gas mitigation and decarbonization, primarily when hydrogen is obtained from renewable sources [19,20].

Fuel cell technology has many other advantages besides its near-zero emissions. These systems offer up to three times the energy conversion efficiency of internal combustion engines, low noise level, long-range, long service life, low maintenance, and short refueling time [21-23]. In addition, using hydrogen energy in electric vehicles is seen as an opportunity to indirectly utilize different fuels, such as natural and biomass [24]. However, the competitiveness of the fuel cell stack is currently low due to the low power density, production cost, and the cost of hydrogen fuel [25,26]. Auxiliary energy storage systems are used in fuel cell electric vehicles to ensure smooth and stable electric motor operation during high load variations that cause slow fuel cell response, performance degradation, and efficiency loss [27]. These systems also convert braking energy into electrical energy with regenerative braking. Auxiliary energy storage systems enable system hybridization with different configurations where elements such as batteries and ultracapacitors can be used together or separately [28]. On the other hand, the high cost of materials and power transmission systems used in fuel cell systems and their durability and design difficulties require further investment and research [29].

Despite some of the problems of fuel cells, it is predicted that these disadvantages will be overcome with rapid developments in technology and intensive research and will soon gain more importance in the energy and transportation sectors [30,31]. Nowadays, there is an increasing interest in experimental and numerical studies on the development of fuel cell components, sub and auxiliary systems, hybrid energy structures, on-vehicle applications, and control methods to make the most of the potential of fuel cells and eliminate their disadvantages [18]. As in many other complex systems, the design, development, and application processes in fuel cell systems are facilitated by mathematical modeling studies. In mathematical simulation and analysis studies, the system can be tested with different boundary conditions and configurations [32-34]. Unlike experimental studies, comparison, prediction, and optimization processes can be carried out with high-accuracy results with less time, cost, and effort [35-37]. In recent years, modeling and analysis studies carried out with the help of software such as MATLAB, ANSYS, and COMSOL have contributed to the development of fuel cell systems. Energy and exergy analysis [38], energy management system design [39], computational fluid dynamics (CFD) based flow analysis [40], electrical modeling [41], and vehicle modeling including driving cycles [42] are some examples of numerical studies on fuel cells.

In this study, an electrically driven bus with a PEM fuel cell intended for urban public transportation is modelled in MATLAB Simulink environment. A linear vehicle model including the resistance forces acting on the vehicle, reference fuel cell stack, reference electric motor, powertrain, and PID speed controller are used in the simulation model. The European Driving Cycle (NEDC) and ECE-R15 driving cycles were used to evaluate the performance parameters of the PEM fuel cell bus. In this way, the speed characteristics of both urban and suburban driving conditions were evaluated, and a comparison was provided. With the model created, the effects of changes in parameters such as total weight, rolling resistance coefficient, gear ratio, and regenerative braking efficiency, which may vary depending on the vehicle, usage, and environmental conditions, on vehicle acceleration performance and hydrogen fuel consumption were examine.

Method

The PEM fuel cell bus simulation model was created through MATLAB Simulink software. This vehicle's energy system, electric motor, power transmission system, resistance forces, and control system are modeled separately and operated simultaneously. The energy required by the vehicle is provided by fuel cell modules and drives the electric motor. The electric motor drives the vehicle under different resistance forces with the help of powertrain and control algorithms. The simulations were carried out according to NEDC and ECE-R15 driving cycles. The changes in the acceleration performance and hydrogen fuel consumption of the vehicle depending on vehicle weight, rolling resistance coefficient, gear ratio, and regenerative braking efficiency were examined.

Energy System Model

The energy requirement of the electric bus is provided by PEM fuel cells. Three PEM fuel cell modules with 50 kW power are used in the vehicle, and the total power is 150 kW. Each fuel cell module can operate with a maximum efficiency of 60% under 20 kW power conditions. The efficiency, power, and hydrogen consumption values of the reference fuel cell module are shown in Figure 1.

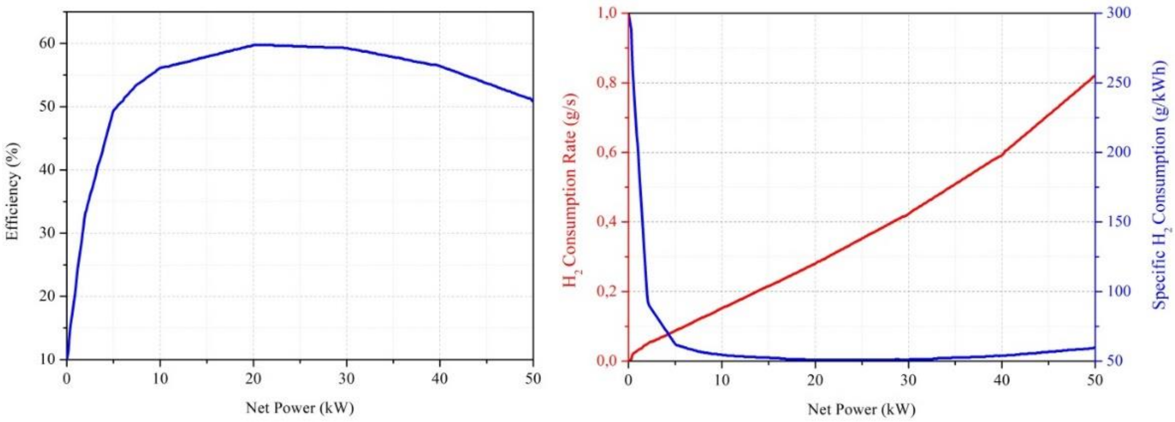

Figure 1. Characteristic graph of fuel cell [43]

The fuel cell stack's highest efficiency is 60% at 60 kW power, and the highest power is 150 kW at 50% efficiency. The fuel cell stack is controlled by a two-stage control algorithm. The fuel cell stack is operated at the maximum efficiency point when the energy demand of the vehicle is low and at the maximum power point when the energy demand reaches critical points. In addition, the fuel cell stack is operated at the maximum efficiency point when the battery charge rate is between 50% and 80%, and at the maximum power point when the battery charge rate is less than 50%. With the effective use of regenerative braking, the fuel cell stack is not charged when the battery charge is above 80%

Electric Motor Model

The power requirement of the bus is generated by Equipmake brand, HTM-3500 model electric motor which can produce maximum 3500 Nm torque and 400 kW power. The torque, speed, and efficiency graphs of the reference electric motor are shown in Figure 2. This motor, which has a maximum speed of 3500 rpm, offers a high efficiency between 84-97% depending on varying torque and speed values in all operating ranges.

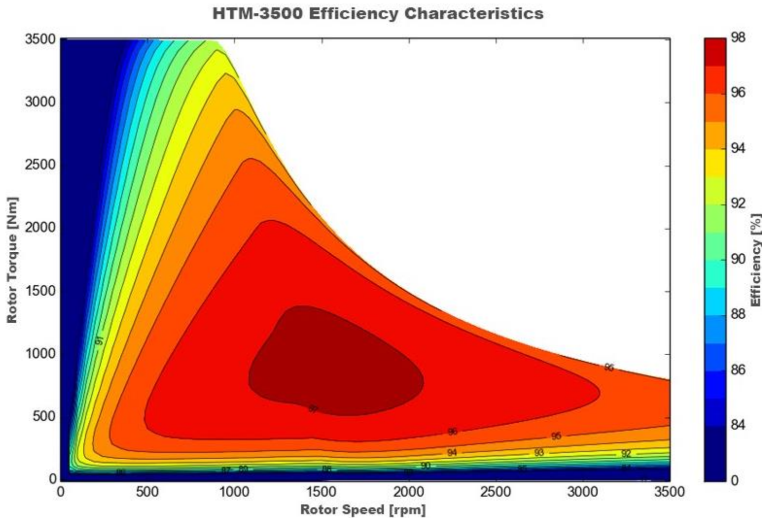

Figure 2. Characteristic graph of Equipmake HTM-3500 electric motor [44]

Powertrain System Model

The power and torque required for the bus's propulsion are generated in the electric motor and transmitted to the wheels with the help of differential and axles. The angular acceleration of the vehicle powertrain is calculated by Equation (1). The angular acceleration of a system is the ratio of the net torque applied to the system (T_{net}) to the sum of the system moments of inertia (J_{total}).

$$\frac{d\omega}{dt} = \frac{T_{net}}{J_{total}} \tag{1}$$

There is a continuous torque input to the powertrain and a torque loss through the system. The torque input is provided by the electric motor and the torque loss is due to the resistance forces acting on the vehicle. Reduction ratio, efficiency and moments of inertia for the electric motor, differential, axles and wheels are also included in the powertrain model. The transfer function of the electric bus powertrain is given in Equation (2).

$$\omega_w = \int_t \frac{T_m i_{fd} \eta_{fd} - T_w}{J_m i_{fd}^2 \eta_{fd} + 2J_a + 8J_w} dt \tag{2}$$

Where T_m and T_w are the engine torque and total resistance torque acting on the wheels respectively, J_m, J_a and J_w are the engine, axle, and wheel moments of inertia respectively, i_{fd} is the differential reduction ratio, and η_{fd} is the differential efficiency. The Simulink model of the powertrain generated using the transfer function and related data inputs is shown in Figure 3.

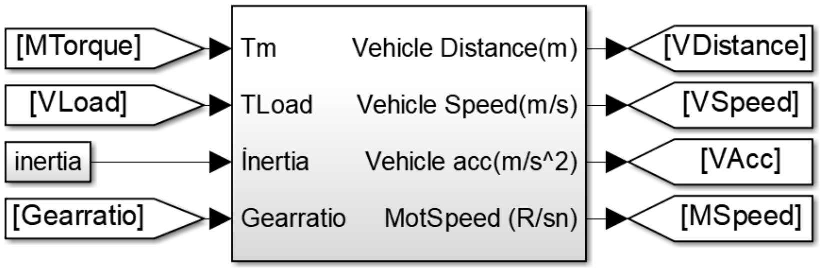

Figure 3. Simulink model of bus powertrain system

Resistance Forces Model

Rolling, acceleration, aerodynamic, and hill resistance forces act on a vehicle during its movement. In the model, the bus is assumed to travel on an inclined road, and the hill resistance forces are neglected. Aerodynamic resistance force is calculated by Equation (3), rolling resistance force by Equation (4), and acceleration resistance force by Equation (5).

$$F_d = 0.5\rho C_d A_f V^2 \tag{3}$$

$$F_r = mgC_r \tag{4}$$

$$F_a = ma \tag{5}$$

In these equations, ρ represents air density, C_d represents aerodynamic resistance coefficient, A_f represents vehicle cross-sectional area, V represents vehicle speed, m represents vehicle weight, C_r represents rolling resistance coefficient, g represents gravitational acceleration, and a represents vehicle acceleration. The Simulink model, where the resistance forces acting on the fuel cell bus are calculated, is shown in Figure 4.

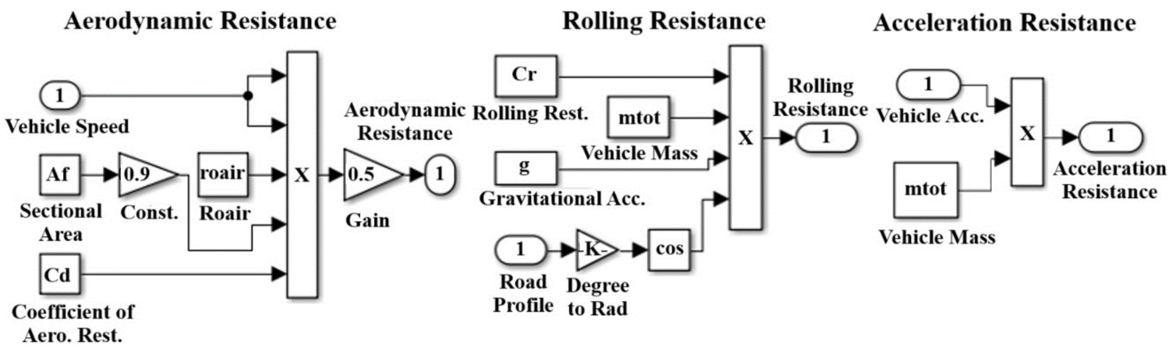

Figure 4. Simulink model of resistance forces

Driving Cycles and Vehicle Control Model

NEDC and ECE-R15 driving cycles were taken as references in the simulations of the fuel cell vehicle. The speed-time graph of the NEDC driving cycle is seen in Figure 5. The first 800 seconds of the NEDC cycle represent urban driving, called the Urban Driving Cycle (UDC) or ECE-R15. In these driving conditions, low vehicle speed and low engine load apply. Driving conditions between 800 and 1180 seconds of the NEDC cycle represent high-speed, long-distance driving called Extra Urban Driving Cycle (EUDC) [45].

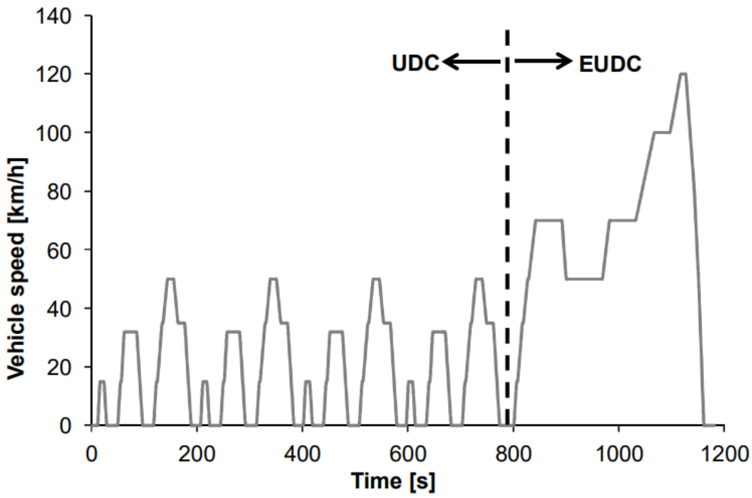

Figure 5. The velocity profile of the NEDC [46]

Vehicle speed is equalized to the reference speed in the driving cycles by PID control of the gas and brake pedals. The Simulink model, in which the gas and brake pedal output signals are required to equalize the vehicle speed to the reference speed, is shown in Figure 6. At full throttle, the bus's acceleration and maximum speed performances can be examined.

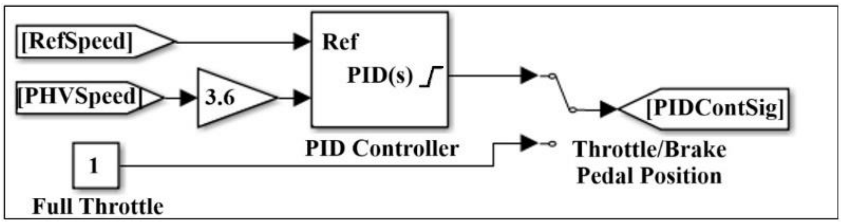

Figure 6. Simulink model of vehicle gas and brake pedal control

Simulation Parameters

Table 1. Simulation parameters [47,48]

Parameters	Units	Values
Vehicle Weight	kg	12550-18000
Wheel Radius	m	0.475
Gear Ratio	-	2-5
Vehicle Cross-Sectional Area	m^2	6.75
Drag Coefficient	-	0.79
Rolling Resistance Coefficient	-	0.008- 0.014
Differantiel Efficiency	%	97
PEM Fuel Cell Power	kW	150
Inverter Efficiency	%	95
Air Density	kg/m^3	1.2
Gravitational Acceleration	m/s^2	9.81
Low Voltage Accessories	W	500
Regenerative Braking Efficiency	%	0-100

Different references were used to determine the parameters depending on the vehicle and road characteristics used in the simulations. The parameters used in the simulation study are presented in Table 1. Here, vehicle weight, gear ratio, rolling resistance coefficient, and regenerative braking efficiency are accepted as variable parameters, and the changes in vehicle acceleration and hydrogen fuel consumption according to these parameters are examined for both driving cycles.

Result and Discussion

The study examined the effects of changes on different parameters such as weight, rolling resistance coefficient, gear ratio, and regenerative braking efficiency of an electric-driven bus with a PEM fuel cell on acceleration performance and hydrogen fuel consumption. Among the variable parameters, the bus weight varies between 12550 and 18000 kg, the rolling resistance coefficient varies between 0.008 and 0.014, the gear ratio varies between 2 and 5, and the regenerative braking efficiency varies between 0% and 100%. All simulation results were obtained and evaluated for NEDC driving cycles, which represent urban and intercity driving conditions, and ECE-R15, which only represent urban driving conditions.

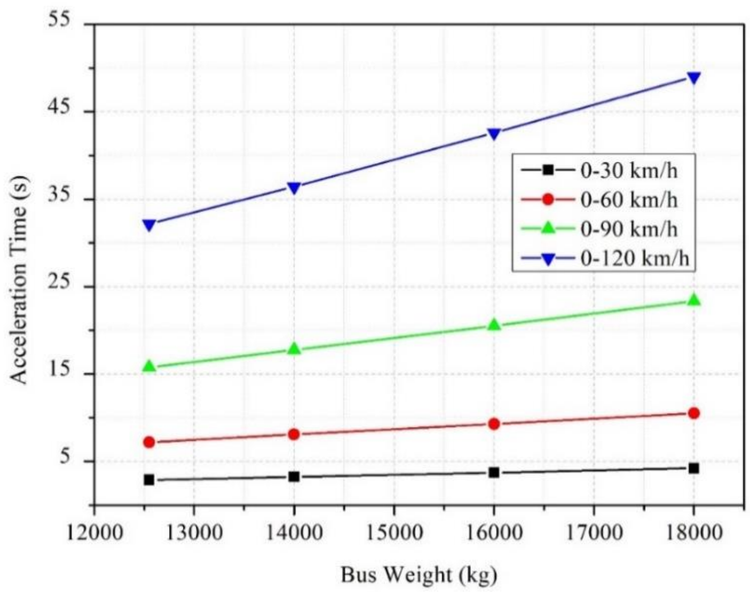

Figure 7. Changes in acceleration performance as a function of bus weight

The effects of the change in bus weight on acceleration performance are seen in Figure 7. The vehicle's acceleration data was obtained for four different final speed values, as seen in the graph. Here, while the bus weight is between 12550 and 18000 kg, the rolling resistance coefficient is assumed as 0.01, the gear ratio is 2, and the regenerative braking efficiency is 50%. When the results are examined, a significant decrease in acceleration performance is observed with increasing vehicle weight. For every 2000 kg increase in vehicle weight caused an increase of approximately 13.7% in 0-30 km/h acceleration time, 13.5% in 0-60 km/h acceleration time, 14.02% in 0-90 km/h acceleration time, and 15.07% in 0-120 km/h acceleration time. The effects of the change in bus weight on hydrogen fuel consumption can be seen in Figure 8. The minimum hydrogen fuel consumption value was achieved at the ECE-R15 driving cycle and 12550 kg vehicle weight. Under these conditions, the PEM fuel cell bus consumes 4.047 kg of hydrogen per 100 km. The simulations carried out according to the NEDC cycle showed a significant increase in fuel consumption compared to the ECE-R15 cycle. Each 2000 kg increase in vehicle weight caused an average increase in hydrogen fuel consumption of 11.1% for the ECE-R15 cycle and 7.43% for the NEDC cycle.

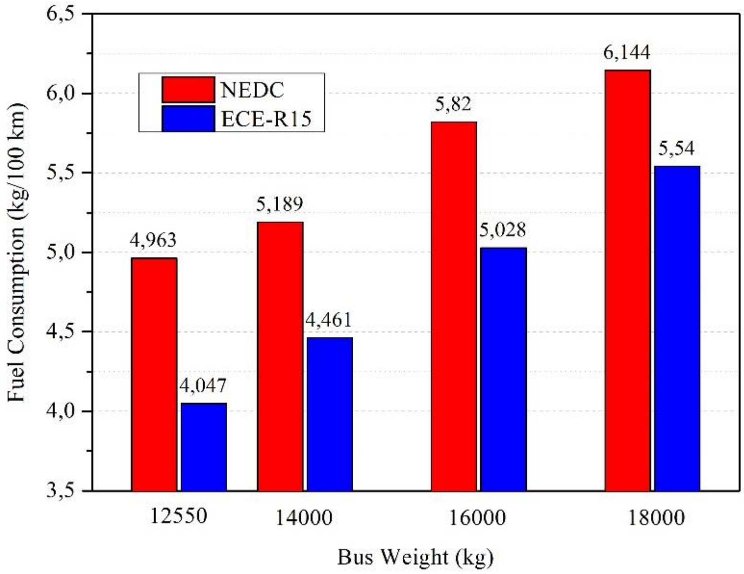

Figure 8. Changes in fuel consumption as a function of bus weight

The effects of the change in the rolling resistance coefficient on acceleration performance are seen in Figure 9. Here, the rolling resistance coefficient takes values between 0.008 and 0.014, while the bus weight is assumed to be 16000 kg, the gear ratio is 2, and the regenerative braking efficiency is 50%. When the results are examined, a slight decrease in acceleration performance is observed with the increase in the rolling resistance coefficient. Each 0.002 increase in the rolling resistance coefficient caused an increase of approximately 0.95% in the 0-30 km/h acceleration time, 1.2% in the 0-60 km/h acceleration time, 2% in the 0-90 km/h acceleration time, and 4% in the 0-120 km/h acceleration time. A linear increase in the acceleration time change was detected depending on the increasing final speed value and rolling resistance coefficient. However, the effect of the rolling resistance coefficient on acceleration performance is relatively low compared to vehicle weight. The effects of the change in rolling resistance coefficient on hydrogen fuel consumption are seen in Figure 10. The minimum hydrogen fuel consumption value was achieved at the ECE-R15 driving cycle and 0.008 rolling resistance coefficient. Under these conditions, the PEM fuel cell bus consumes 4.493 kg of hydrogen per 100 km. As in the simulations carried out based on vehicle weight, a significant increase in fuel consumption was observed in the simulations carried out in the NEDC driving cycle. Each 0.002 increase in the rolling resistance coefficient caused an average increase of 8.9% in hydrogen fuel consumption for the ECE-R15 cycle and 7.42% for the NEDC cycle.

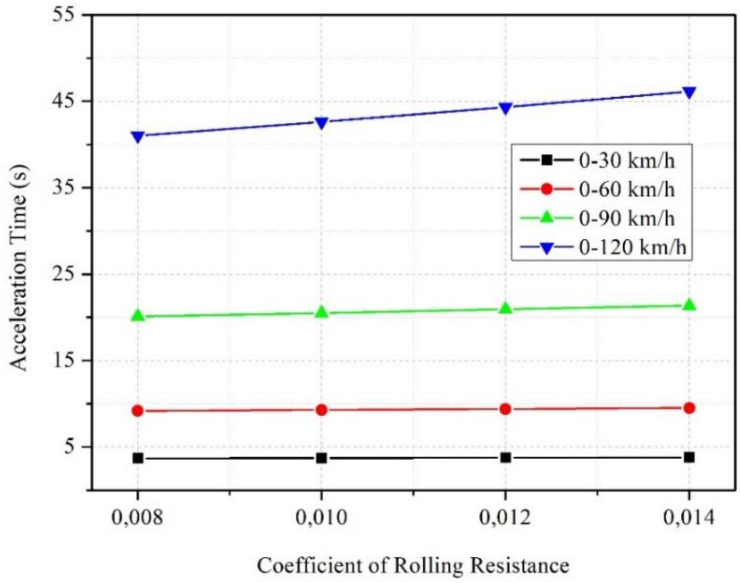

Figure 9. Changes in acceleration performance as a function of coefficient of rolling resistance

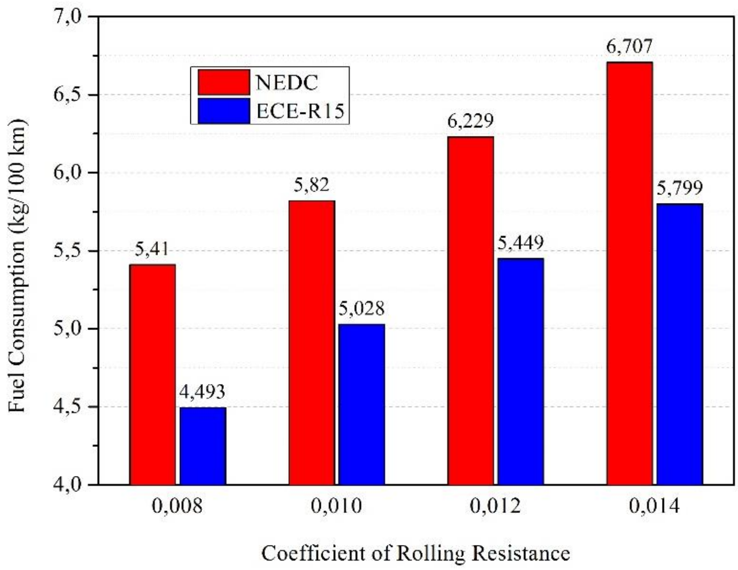

Figure 10. Changes in fuel consumption as a function of coefficient of rolling resisteance

The effects of the change in gear ratio on acceleration performance can be seen in Figure 11. Here, the gear ratio takes values between 2 and 5, the bus weight is assumed to be 16000 kg, the rolling resistance coefficient is 0.01, and the regenerative braking efficiency is 50%. In the simulations, the maximum gear ratio was considered to be 5. It has been observed that the acceleration performance of the fuel cell bus is insufficient at larger gear ratios. The figure shows that the best acceleration performance was obtained when the gear ratio was 5. Each 1 increase in the gear ratio caused an increase of approximately 28.2% in 0-30 km/h acceleration time, 22.8% in 0-60 km/h acceleration time, 13.4% in 0-90 km/h acceleration time, and 5.12% in 0-120 km/h acceleration time. The effects of the change in gear ratio on hydrogen fuel consumption can be seen in Figure 12. The minimum hydrogen fuel consumption value was achieved when the ECE-R15 driving cycle and gear ratio was 5. Under these conditions, the PEM fuel cell bus consumes 5.028 kg of hydrogen per 100 km. As in the simulations based on vehicle weight and rolling resistance coefficient, a significant increase in fuel consumption occurred in the simulations carried out in the NEDC driving cycle. Each 1 increase in the gear ratio resulted in an average decrease of 1.31% in hydrogen fuel consumption for the ECE-R15 cycle and 0.76% for the NEDC cycle. In the simulation and driving cycle conditions, it was determined that the gear ratio had significant effects on acceleration performance, but had no significant effect on fuel consumption.

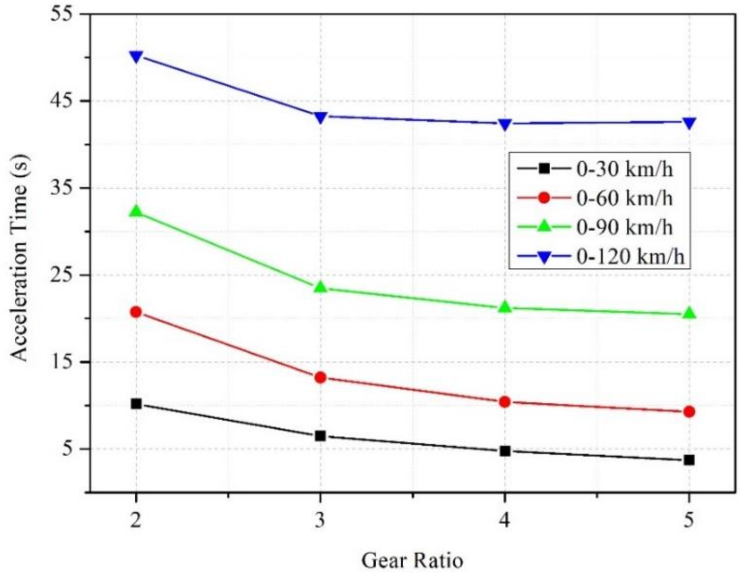

Figure 11. Changes in acceleration performance as a function of gear ratio

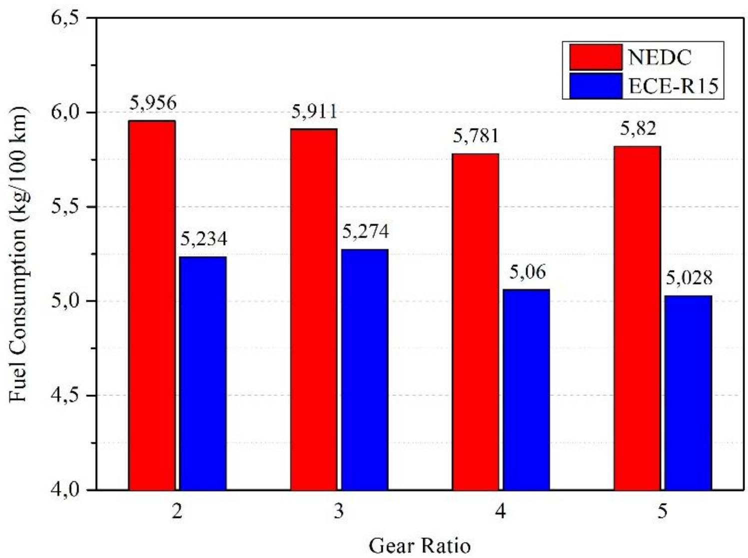

Figure 12. Changes in fuel consumption as a function of gear ratio

Finally, the effects of the change in regenerative braking efficiency on hydrogen fuel consumption can be seen in Figure 13. Here, while the regenerative braking efficiency takes values between 0% and 100%, the bus weight is assumed to be 16000 kg, the rolling resistance coefficient is 0.01, and the gear ratio is 2. With increased regenerative braking efficiency, significant improvements were observed in hydrogen fuel consumption for both the NEDC and ECE-R15 driving cycles. The minimum hydrogen fuel consumption value was achieved at the ECE-R15 driving cycle and 100% regenerative braking efficiency. Under these conditions, the PEM fuel cell bus consumes 3.635 kg of hydrogen per 100 km. Each 25% increase in regenerative braking efficiency resulted in an average hydrogen fuel consumption reduction of 12.75% for the ECE-R15 cycle and 8.65% for the NEDC cycle.

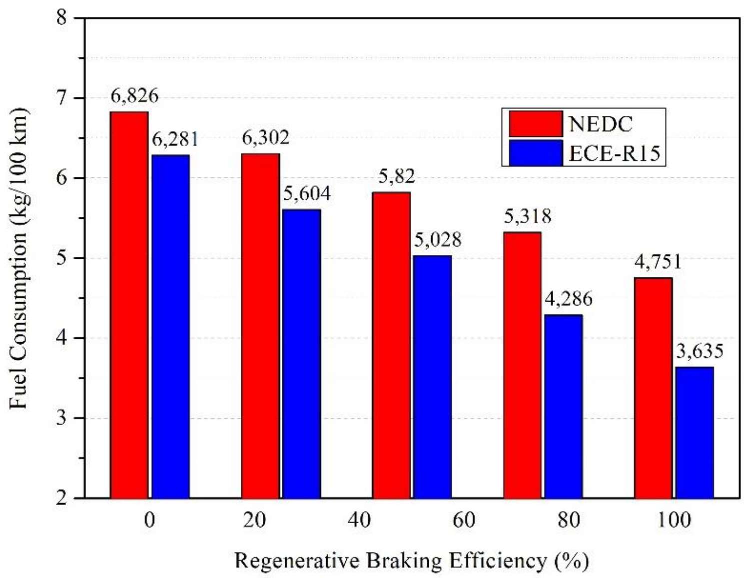

Figure 13. Changes in fuel consumption as a function of regenerative braking efficiency

Conclusion

In the simulation study, an electrically driven bus with a PEM fuel cell was modeled using MATLAB Simulink software. This vehicle's acceleration performance and hydrogen fuel consumption values were examined depending on changes in vehicle weight, rolling resistance coefficient, gear ratio, and regenerative braking efficiency. Simulation conditions were created from NEDC and ECE-R15 driving cycles, covering urban and extra-urban driving conditions. As a result of the study, an average of 14.07% increase in acceleration times was observed for every 2000 kg increase in the weight of the fuel cell bus. For every 0.002 increase in the rolling resistance coefficient value, there was an average 2% increase in acceleration times. It has been observed that acceleration times increase by an average of 17.4% for every decrease in the gear ratio value. An increase of 2000 kg in bus weight resulted in an average increase of 9.26% in hydrogen fuel consumption in the NEDC and ECE-R15 driving cycles. For every 0.002 increase in rolling resistance coefficients, an average increase of 8.16% in fuel consumption was observed. Each increase in gear ratio provided an average of 1.03% improvement in hydrogen fuel consumption. When regenerative braking efficiency was 100% in the NEDC driving cycle, total fuel savings reached 30%. In the ECE-R15 driving cycle, when the regenerative braking efficiency was 100%, the total fuel saving was 42%.

References

[1] United Nations Department of Economic and Social Affairs, Population Division. World Population Prospects 2022: Summary of Results. UN DESA/POP/2022/TR/NO. 3, 2022.

[2] Arslan, T.A.; Kocakulak, T. A Comprehensive Review on Stirling Engines. Engineering Perspective 2023, 3, 42-56, doi: 10.29228/eng.pers.66847.
[3] International Energy Agency. Technology Roadmap - Hydrogen and Fuel Cells. 2016.
[4] Kocakulak, T.; Arslan, T.A.; Şahin, F.; Solmaz, H.; Ardebili, S.M.S.; Calam, A. Determination of Optimum Operating Parameters of MWCNT-Doped Ethanol Fueled HCCI Engine for Emission Reduction. Science of the Total Environment 2023, 895, 165196, doi: 10.1016/j.scitotenv.2023.165196.
[5] Kalghatgi, G.T. Developments in Internal Combustion Engines and Implications for Combustion Science and Future Transport Fuels. Proceedings of the Combustion Institute 2015, 35, 101-115, doi: 10.1016/j.proci.2014.10.002.
[6] U.S. Energy Information Administration. Short-Term Energy Outlook. 2023.
[7] (EU) CD. International Agreements 2016. 2016, 6-8.
[8] European Commission. European Climate Law. Official Journal of the European Union 2021, June, 17.
[9] Boyacıoğlu, N.M.; Kocakulak, T.; Batar, M.; Uyumaz, A.; Solmaz, H. Modeling and Control of a PEM Fuel Cell Hybrid Energy System Used in a Vehicle with Fuzzy Logic Method. International Journal of Automotive Science and Technology 2023, 7, 295-308, doi: 10.30939/ijastech..1340339.
[10] Tanç, B.; Arat, H.T.; Conker, Ç.; Baltacıoğlu, E.; Aydın, K. Energy Distribution Analyses of an Additional Traction Battery on Hydrogen Fuel Cell Hybrid Electric Vehicle. International Journal of Hydrogen Energy 2020, 45, 26344-26356, doi: 10.1016/j.ijhydene.2019.09.241.
[11] Montoya, A.; Guéret, C.; Mendoza, J.E.; Villegas, J.G. The Electric Vehicle Routing Problem with Nonlinear Charging Function. Transportation Research Part B: Methodological 2017, 103, 87-100, doi: 10.1016/j.trb.2017.02.004.
[12] Jin, C.; Tang, C.; Ghosh, P. Optimizing Electric Vehicle Charging: A Customer's Perspective. IEEE Transactions on Vehicular Technology 2013, 62, 2919-2927, doi: 10.1109/TVT.2013.2251023.
[13] Dinh, T.X.; Thuy, L.K.; Tien, N.T.; Dang, T.D.; Ho, C.M.; Truong, H.V.A.; Dao, H.V.; Do, T.C.; Ahn, K.K. Modeling and Energy Management Strategy in Energetic Macroscopic Representation for a Fuel Cell Hybrid Electric Vehicle. Journal of Drive and Control 2019, 16, 80-90, doi: 10.7839/ksfc.2019.16.2.080.
[14] IEA. Renewable Electricity Generation by Source, World 1990–2018. Available online: https://www.iea.org/data-and-statistics/ (accessed on 20 December 2023).
[15] Trinh, H.A.; Truong, H.V.A.; Ahn, K.K. Development of Fuzzy-Adaptive Control Based Energy Management Strategy for PEM Fuel Cell Hybrid Tramway System. Applied Sciences 2022, 12, 3880, doi: 10.3390/app12083880.
[16] Zhou, Y.; Li, H.; Ravey, A.; Péra, M.C. An Integrated Predictive Energy Management for Light-Duty Range-Extended Plug-In Fuel Cell Electric Vehicle. Journal of Power Sources 2020, 451, 227780, doi: 10.1016/j.jpowsour.2020.227780.
[17] Stempien, J.P.; Chen, S.H. Comparative Study of Fuel Cell, Battery and Hybrid Buses for Renewable Energy Constrained Areas. Journal of Power Sources 2017, 340, 347-355, doi: 10.1016/j.jpowsour.2016.11.089.
[18] Motapon, S.N.; Tremblay, O.; Dessaint, D.A. A Generic Fuel Cell Model for the Simulation of Fuel Cell Vehicles. 2009 IEEE Vehicle Power and Propulsion Conference 2009, Dearborn, MI, USA, 1722-1729, doi: 10.1109/VPPC.2009.5289692.
[19] Bishop, J.D.K.; Martin, N.P.; Boies, A.M. Cost-Effectiveness of Alternative Powertrains for Reduced Energy Use and CO2 Emissions in Passenger Vehicles. Applied Energy 2014, 124, 44-61, doi: 10.1016/j.apenergy.2014.02.019.
[20] Kocakulak, T.; Arslan T.A. Investigation of the Use of Fuel Cell Hybrid Systems for Different Purposes, Engineering Perspective 2023, 1, 1-8, doi: 10.29228/eng.pers.68466.
[21] Soumeur, M.A.; Gasbaoui, B.; Abdelkhalek, O.; Ghouili, J.; Toumi, T.; Chakar, A. Comparative Study of Energy Management Strategies for Hybrid Proton Exchange Membrane Fuel Cell Four Wheel Drive Electric Vehicle. Journal of Power Sources 2020, 462, 228167, doi: 10.1016/j.jpowsour.2020.228167.
[22] Lin, R.; Xiong, F.; Tang, W.C.; Técher, L.; Zhang, J.M.; Ma, J.X. Investigation of Dynamic Driving Cycle Effect on the Degradation of Proton Exchange Membrane Fuel Cell by Segmented Cell Technology. Journal of Power Sources 2014, 260, 150-158, doi: 10.1016/j.jpowsour.2014.03.003.
[23] Luciani, S.; Tonoli, A. Control Strategy Assessment for Improving PEM Fuel Cell System Efficiency in Fuel Cell Hybrid Vehicles. Energies 2022, 15, 2004, doi: 10.3390/en15062004.
[24] Ehsani, M.; Gao, Y.; Longo, S; Ebrahimi, K. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles. CRC Press 2018.
[25] Sergi, F.; Andoloro, L.; Napoli, G.; Randazzo, N.; Antonucci, V. Development and Realization of a Hydrogen Range Extender Hybrid City Bus. Journal of Power Sources 2014, 250, 286-295, doi: 10.1016/j.jpowsour.2013.11.006.

[26] Koteswararao, V.K.; Srinivasulu, G.N.; Velasala, V. A Review on Energy Allocation of Fuel Cell/Battery/Ultracapacitor for Hybrid Electric Vehicles. International Journal of Energy Research 2018, 42, 4263-4283, doi: 10.1002/er.4166.
[27] Fu, Z.; Zhu, L.; Tao, F.; Si P.; Sun, L. Optimization Based Energy Management Strategy for Fuel Cell/Battery/Ultracapacitor Hybrid Vehicle Considering Fuel Economy and Fuel Cell Lifespan. International Journal of Hydrogen Energy 2020, 45, 8875-8886, doi: 10.1016/j.ijhydene.2020.01.017.
[28] Bartolucci, L.; Cennamo, E.; Cordiner, S.; Mulone. V.; Pasqualini, F.; Boot, M.A. Digital Twin of a Hydrogen Fuel Cell Hybrid Electric Vehicle: Effect of the Control Strategy on Energy Efficiency. International Journal of Hydrogen Energy 2023, 48, 20971-20985, doi: 10.1016/j.ijhydene.2022.11.283.
[29] Ma, S.; Lin, M.; Lin, T.; Lan, T.; Liao, X.; Maréchal, F.; Herle, J.V.; Yang, Y.; Dong, C.; Ligang W. Fuel Cell-Battery Hybrid Systems for Mobility and Off-Grid Applications: A Review. Renewable and Sustainable Energy Reviews 2021, 135, 110119, doi: 10.1016/j.rser.2020.110119.
[30] Saadat, N.; Dhakal, H.N.; Tjong, J.; Jaffer, S.; Yang, W.; Sain, M. Recent Advances and Future Perspectives of Carbon Materials for Fuel Cell. Renewable and Sustainable Energy Reviews 2021, 138, 110535, doi: 10.1016/j.rser.2020.110535.
[31] İnci, M. Future Vision of Hydrogen Fuel Cells: A Statistical Review and Research on Applications, Socio-Economic Impacts and Forecasting Prospects. Sustainable Energy Technologies and Assessments 2022, Part C, 102739, doi: 10.1016/j.seta.2022.102739.
[32] Solmaz, H.; Kocakulak, T. Determination of Lithium Ion Battery Characteristics for Hybrid Vehicle Models. International Journal of Automotive Science And Technology 2020, 4, 264-271, doi: 10.30939/ijastech..723043.
[33] Arslan, T.A.; Solmaz, H. M3 Kategorisi Bir Otobüs Tasarımı ve Yapısal Analizleri. International Conference on Technology and Science 2018, 1, 342-351.
[34] Karaman, M.; Korucu, S. Modeling the Vehicle Movement and Braking Effect of the Hydrostatic Regenerative Braking System. Engineering Perspective 2023, 3, 18-26, doi: 10.29228/eng.pers.69826.
[35] Kocakulak, T.; Solmaz, H. Control of Pre and Post Transmission Parallel Hybrid Vehicles with Fuzzy Logic Method and Comparison with Other Power Systems. Journal of the Faculty of Engineering and Architecture of Gazi University 2020, 35, 2269-2286, doi: 10.17341/gazimmfd.709101.
[36] Arslan, T.A.; Solmaz, H.; İpci, D.; Aksoy, F. Investigation of the Effect of Compression Ratio on Performance of a Beta Type Stirling Engine with Rhombic Mechanism by CFD Analysis. Environmental Progress & Sustainable Energy 2023, 42, e14076, doi: 10.1002/ep.14076.
[37] Karakaş, O.; Şeker, U.B.; Solmaz, H. Modeling of an Electric Bus Using MATLAB/Simulink and Determining Cost Saving for a Realistic City Bus Line Driving Cycle. Engineering Perspective 2021, 1, 52-62, 10.29228/eng.pers.51422.
[38] Gimba, I.D.; Abdulkareem, A.S.; Jimoh, A.; Afolabi, A.S. Theoretical Energy and Exergy Analyses of Proton Exchange Membrane Fuel Cell by Computer Simulation. Journal of Applied Chemistry 2016, 2684919, 10.1155/2016/2684919.
[39] Shen, D.; Lim, C.C.; Shi, P. Robust Fuzzy Model Predictive Control for Energy Management Systems in Fuel Cell Vehicles. Control Engineering Practice 2020, 98, 104364, doi: 10.1016/j.conengprac.2020.104364.
[40] Ngetich, C.C.; Mutua, J.; Kareru, P.; Karanja, K.; Wanjiru, E. Integrated Taguchi and Response Surface Methods in Geometric and Parameter Optimization of PEM Fuel Cells. Fuel Cells 2023, 23, 324-337, doi: 10.1002/fuce.202200209.
[41] Belhaj, F.Z.; Fadil, H.E.; Idrissi, Z.E.; Intidam, A.; Koundi, M.; Giri, F. New Equivalent Electrical Model of a Fuel Cell and Comparative Study of Several Existing Models with Experimental Data from the PEMFC Nexa 1200 W. Micromachines 2021, 12, 1047, doi: 10.3390/mi12091047.
[42] Changizian, S.; Ahmadi, P.; Raeesi, M.; Javani, N. Performance Optimization of Hybrid Hydrogen Fuel Cell-Electric Vehicles in Real Driving Cycles. International Journal of Hydrogen Energy 2020, 45, 35180-35197, doi: 10.1016/j.ijhydene.2020.01.015.
[43] Ansarey, M.; Panahi, M.S.; Ziarati, H.; Mahjoob, M. Optimal Energy Management in a Dual-Storage Fuel-Cell Hybrid Vehicle Using Multi-Dimensional Dynamic Programming. Journal of Power Sources 2014, 250, 359-371, doi: 10.1016/j.jpowsour.2013.10.145.
[44] Equipmake. HTM-3500, Performance. Available online: https://equipmake.co.uk/products/htm-3500/ (accessed on 20 December 2023).
[45] Kıyaklı, A.O.; Solmaz, H. Modeling of an Electric Vehicle with MATLAB/Simulink. International Journal of Automotive Science and Technology 2018, 2, 9-15, doi: 10.30939/ijastech..475477.
[46] Bielaczyc, P.; Szczotka, A.; Woodburn, J. Carbon Dioxide Emissions and Fuel Consumption from Passenger Cars Tested Over the NEDC and WLTC–An Overview and Experimental Results From

Market-Representative Vehicles. IOP Conference Series: Earth and Environmental Science 2019, 214, 012136, doi: 10.1088/1755-1315/214/1/012136.
[47] Khanipour, A.; Ebrahimi, K.M.; Seale, W.J. Conventional Design and Simulation of an Urban Hybrid Bus. International Journal of Mechanical and Mechatronics Engineering 2007, 1, 146-152, doi: 10.5281/zenodo.1074900.
[48] Wu, X.; Hu, X.; Yin, X.; Li, L.; Zeng, Z.; Pickert, V. Convex Programming Energy Management and Components Sizing of a Plug-In Fuel Cell Urban Logistics Vehicle. Journal of Power Sources 2019, 423, 358-366, doi: 10.1016/j.jpowsour.2019.03.044.