International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 14, No. 4, December 2023, pp. 1911~1918
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i4.pp1911-1918

Evaluation of energy management system of a hybrid energy source in EV

Rachid Touileb, Ahmed Abbou
Department of Electrical Engineering, Mohammadia School of Engineering, Mohammed V University, Rabat, Morocco

Article Info

Article history:

Received Feb 26, 2023
Revised Apr 15, 2023
Accepted May 3, 2023

Keywords:

Battery
Energy management strategies
Fuel cell
Hybrid vehicle
MATLAB/Simulink
Simulation

ABSTRACT

This paper presents a comparative study of different energy management strategies and technologies of fuel-cell hybrid electric vehicles integrating a proton exchange membrane fuel cell device in addition to a lithium-ion battery as a secondary energy source. Therefore, an experimental analysis is carried out to seek the successful hybrid powertrains considering the hydrogen utilization in fuel cells and state-of-charge regulation in Li-ion batteries. Different approaches were simulated using a developed vehicle simulator in MATLAB/Simulink. The simulations were performed using three standard driving cycles in which a second study based on energy management strategies tested was presented and analyzed. Simulation's results show the superiority and economic success of the proposed technology and method, especially the FSBS and MEPT management strategies due to the successful use of the sources and the significant optimization in terms of hydrogen consumption while maintaining optimal Li-ion battery usage.

Corresponding Author:

Rachid Touileb
Department of Electrical Engineering, Mohammadia School of Engineering, Mohammed V University
Rabat 10090, Morocco
Email: Touilebrachid1@gmail.com

NOMENCLATURE

$P_{load}(t)$ (W)	: Load power	f_{C_1}(Hz)	: The cut-off frequency of the first filter
$P_{bat}(t)$ (W)	: Battery power	f_{C_2}(Hz)	: Cut-off frequency of the second filter
$P_{FC}(t)$ (W)	: Fuel cell power	V_{bat} (V)	: Voltage of battery
P_{FC_max} (W)	: Maximal fuel cell power	Q_{bat} (Ah)	: Capacity of battery
P_{FC_min} (W)	: Minimal fuel cell power	$Cons_{H_2}$ (g)	: Hydrogen consumption total
N_{cell}	: Fuel cell number	$Cons_{H_{2}bat}$(g)	: Hydrogen consumption of battery
P_{FCave} (W)	: Average fuel cell power	$Cons_{H_{2}ave}$(g)	: Average hydrogen consumption
$SoC(t)$(%)	: State of charge of the battery	f_{SoC}	: Weighting factor
SoC_{min} (%)	: Minimal state of charge of the battery	R_{bat} (Ω)	: Battery internal resistance
SoC_{max}(%)	: Maximal state of charge of the battery	LHV(Kj/g)	: LHV is the hydrogen lower heating value (120 Kj/g)
η_{bat}	: The charge and discharge efficiency	$\eta(P_{FC}(t))$	: Fuel cell efficiency
E_0 (V)	: Open circuit voltage	$V_{FC}(V)$	: Voltage of fuel cell

1. INTRODUCTION

People need energy more and more on their daily basis due to increased technological advances and population growth. Using traditional energy sources in transportation and engines creates significant problems for the environment and society. These problems include air pollution, critical concerns today include diminishing energy resources and climate change. New, more environmentally, friendly, affordable, safe, and limitless energy sources are needed. Fuel cell technology uses a process called electrochemical oxidation to generate power. Its name is a popularized term for an environmentally sustainable energy source. It's a clean energy source classified as green in terms of durability and low emissions.

A proton exchange membrane fuel cell (PEMFC) is a fuel cell powered by a membrane composed of a hydrogenated, protonated and pure fuel derived, as well as detailed in [1]–[3]. There are many issues with the use of lithium-ion batteries in many different industries, including automobile, aerospace, aviation, and energy storage. Car's power sources come from the automotive industry; this includes the preference for traction engines and fuel requirements for manufacturing. PEMFCs engines have the most control over energy flow among all other FC systems in the industry. To meet a minimum required operating temperature, which necessitates a high density of electric power output. Higher costs, short lifespans, and slow-motion responses are also noteworthy in regard to PEMFCs. A vehicle that requires substantial electric power to start out can be considered also as a major drawback associated with this technology. Adding another power source benefits from their combined power advantages with minimal drawbacks. In addition to that, the hybridization of A FC stores its peak power, usually in the form of high frequency and amplitude. In some cases, these peaks are stored with a larger energy capacity. Lithium-ion batteries (LiBs) are frequently employed with huge capacities as exposed in [4], [5]. This necessitates a decrease in fluctuating rates, as stated by FC. Electric vehicles (EVs) have long life expectancies compared to other energy storage options. This makes them a great choice for battery power. Combining FC with LiB gives optimum results for this field [6], [7]. Furthermore, this combination provides the greatest power and charge density. Additional research is needed on the device's design and system management in order to realize an output power balanced by the ability to recover braking energy as well. This new innovation requires further investigation of its potential benefits, as well as additional improvements that are necessary to investigate all the positive results of this technology.

This paper includes a hybrid vehicle equipped by a PEMFC power source and a secondary battery for maximum power, and fast driving with efficient regenerative braking power process. The main purpose of this paper is to select the optimal algorithm from the three analyzed approaches to economize the power flow and hydrogen consumption according to state-of-charge (SoC) manipulation. This system tries to explain and simulate a PEMFC source with a DC-DC converter [8], [9]. The main goal is to reproduce similar characteristics as in effective conditions in reality: temperature change, fuel pressure and water content of the membrane. The rest of the paper presents the powertrain architecture and its system model with the presentation of the different energy management strategies studied detailed in the second section. Finally, simulation results of these methods through different driving cycles are presented and analyzed in section 3.

2. METHOD

The energy management methods try to explain how energy is distributed between batteries and fuel cells following some rules and criteria determined and specified by the vehicle's system as shown in [10]–[13]. They can optimize the fuel cell capacities and consumption depending on energy demands as described in [14], [15]. For this purpose, the model adopted is represented by four main blocks as shown in Figure 1.

This article presents three energy management strategies and simulates them in MATLAB/Simulink using the model previously shown in Figure 1. These methods attempt to minimize hydrogen consumption by optimizing the use of the battery as secondary energy source (SSE) [16], [17]. The rationale for these methods and their goals are described later in this section.

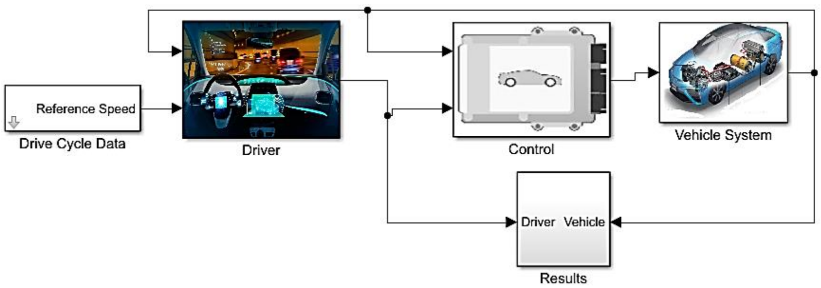

Figure 1. Representation of the fuel cell hybrid vehicle in Simulink

2.1. Maximum efficiency strategy

This process determines the best efficiency point for a given circuit. This method called maximum efficiency point tracking (MEPT) (uses the same method to define the maximum power point of wind turbines; commonly cited as maximum power point tracking (MPPT). This strategy uses data about FC efficiency maps to identify the best conditions for that particular circuit. The main function of this emergency message string is to display the cost-effective price of a limited time-frame usage of hydrogen. As the energy supply changes, the performance chart of the FC comes into view. Employee's performance is impacted by the temperature in the surrounding environment. In order to counter this, this model proposes a load-follower method that takes advantage of high effectiveness while keeping workplaces regulated [18]–[20]. The Figure 2 shows the manner how the numbers of working points are determined by FC.

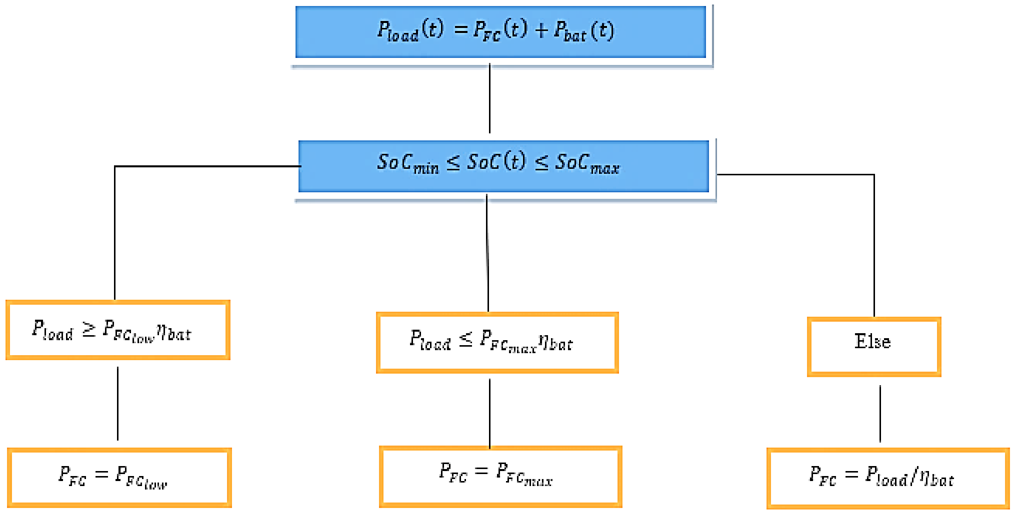

Figure 2. Organigram of the MEPT calculation approach

2.2. Frequency separation-based strategy

Functional capacitance is reduced by filtering the bus voltage as shown in Figure 3. Doing this produces the functional conduction mechanism that uses a low pass filter to relate functional charge. By separating the source's power generation frequency, each component is assigned its frequency to handle the particular demands of each source. This electrical machine system provides a range of power supplies and addresses how sources are diverse in functionality.

The frequency-specific power spectrum of the sources motivates a separation-based energy regulation method. Figure 3 gives also more details on how this system operates. Two different loads with variable power requirements help to determine the system's necessary components. The two low-pass filters have respectively two cut-off frequencies f_{C_1} and f_{C_2}, with the first filter being used to generate frequency harmonics $P_{FC_{fsbs}}$ in the FC device less than the other filter's cut-off frequency. The next filter is supplied by the variation value separating the component's FC and the load power, which creates moderate frequency power $P_{bat_{fsbs}}$ for use in battery sizing as developed in [21]–[23].

The mission is to find and identify the corresponding sets of each source and its size through the frequencies f_{C_1} and f_{C_2}. Two powers are derived from (1) and (2):

$$P_{FC_{fsbs}} = \frac{2\pi f_{C_1}}{2\pi f_{C_1} + s} P_{load} \quad (1)$$

$$P_{bat_{fsbs}} = \frac{2\pi f_{C_2}}{2\pi f_{C_2} + s} \left(P_{load} - P_{FC_{fsbs}}\right) \quad (2)$$

The FC's lifetime is extended when it responds to low frequencies while the battery responds to high frequencies. The multi-level response filtering in the FC device is ordered by the tuning parameter. The T of a low-pass filter is 20 seconds. This step necessitates to be selected correctly regarding the FC's reaction time.

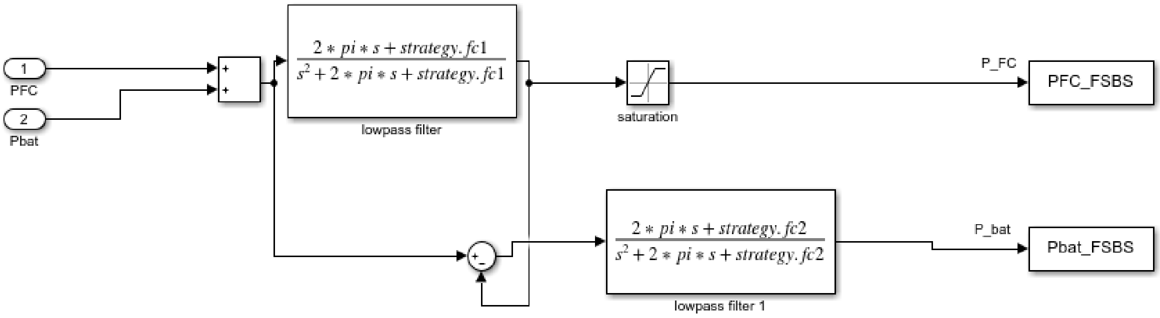

Figure 3. Functional scheme of frequency separation method FSBS

2.3. An improved online optimal control strategy

To properly manage power, hybrid electric vehicles (HEVs) costing functions need to be added and in the minimum values possible. Some of them are well specified, with a short timing, limited monitoring commitment, difference of state variables and others limitations. Additional control and cost features are necessary to properly manage power in HEVs. The (3) shows the cost function as a result of:

$$J = \int_{t_0}^{t_f} f(x(t), u(t), t) \tag{3}$$

With: x(t) represents the state vector, u(t) refers to the input vector.

LiB SoC stands for the state vector. It's the term used to describe system dynamics; it's a list of values given by the system. The input vector is u(t), the primary and finishing driving cycle times are t_0 and t_f, and x(t) is the state vector. Using the power generated by FC as input and the state vector, the relation governing the system dynamics is described in [24].

$$SoC = -\frac{V_{bat} - \sqrt{V_{bat}^2 - 4R_{bat}P_{bat}}}{2Q_{bat}R_{bat}} \tag{4}$$

The demand for power is met with a hybrid system that provides equal distribution as (5):

$$P_{load}(t) = P_{FC}(t) + P_{bat}(t) \tag{5}$$

with the following constraints:

$$P_{FC\_min} \leq P_{FC} \leq P_{FC\_max} \tag{6}$$

$$SoC_{min} \leq SoC(t) \leq SoC_{max} \tag{7}$$

The constraints are presented in (6) and (7). Put restrictions to the FC and battery powers in (6) and (7) states the device's power and fuel constraints in order to avoid damage. This strategy reduces fuel consumption at set intervals. Calculating the power consumption of a fuel tank in line with a car's production potential and total fuel output via a fuel cell converter (FC) [25], [26], as in (8), which minimizes costs:

$$Cons_{H_2}(t) = \int \frac{P_{FC}(t)}{\eta(P_{FC}(t)) * LHV} dt \tag{8}$$

The correlation between the FC efficiency and its rated voltage is expressed by the (9):

$$\eta(P_{FC}(t)) = \frac{V_{FC}(t)}{1.48N_{cell}} \tag{9}$$

To allow the process of charging the FC by the batteries and the problem optimization resulting from the ECMS, it is necessary to add a cost function to the system as the following:

$$Cons_{H_{2opt}}(t) = Cons_{H_2} + f_{SoC}Cons_{H_{2bat}} \tag{10}$$

$$Cons_{H_{2bat}} = \frac{Cons_{H_2ave}P_{bat}}{\eta_{bat}P_{FCave}} \tag{11}$$

with:

$$\eta_{bat} = \begin{cases} \frac{3}{2} + \sqrt{1 - \frac{4R_{bat}P_{bat}}{E_0^2}}, & P_{bat} \geq 0 \\ \frac{2}{1 + \sqrt{1 - \frac{4R_{bat}P_{bat}}{E_0^2}}}, & P_{bat} < 0 \end{cases} \quad (12)$$

$$f_{SoC} = \begin{cases} \left(1 - \frac{2(SoC - SoC_0)}{SoC_{MAX} - SoC_{MIN}}\right)^4 & , SoC_{MIN} \leq SoC \leq SoC_{MAX} \\ \left(1 - \frac{2(SoC - SoC_0)}{SoC_{MAX} - SoC_{MIN}}\right)^{20} & , SoC_{MAX} \leq SoC \quad SoC \leq SoC_{MIN} \end{cases} \quad (13)$$

3. RESULTS AND DISCUSSION

To highlight the performance of the suggested model, three standard driving cycles, namely: NEDC, FTP and WLTP were simulated and compared before and after the development and the application of the different energy management strategies. The three energy management methods simulated and analyzed are respectively FSBS, MEPT and IOOCS. Figures 4, 5 and 6 show the results of the simulations in the three-driving cycle tested.

These figures show the description of different driving cycles results, respectively the speed spectrum, the variation of the state of charge, the full cell power, and the battery power. Then will be presented the different results of the answer system with each management energy method applied. To facilitate the comparison of the results, we have drawn up a table of the values obtained in the various methods tested by focusing on two characteristic instants in each driving cycle by way of illustration and the average consumption.

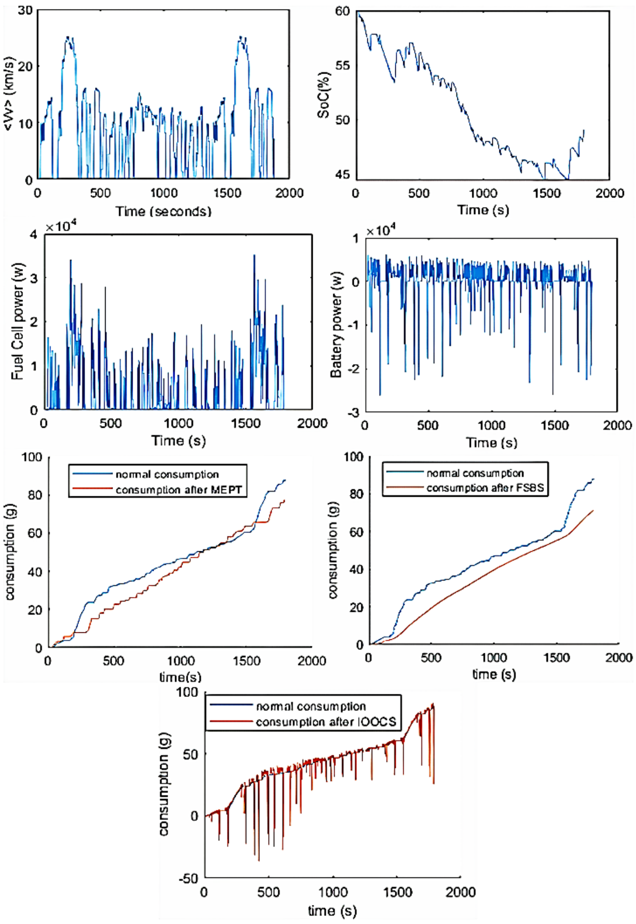

Figure 4. The results of the FTP driving cycle

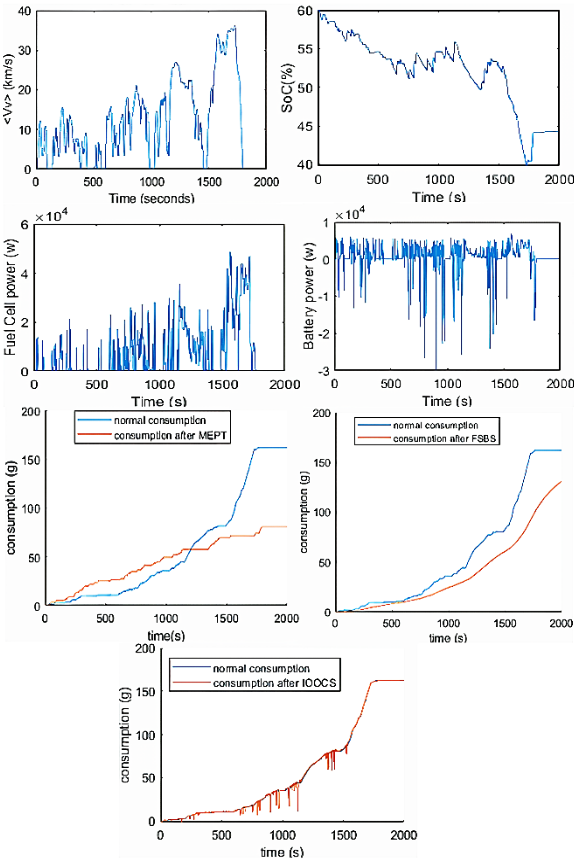

Figure 5. The results of the WLTP driving cycle

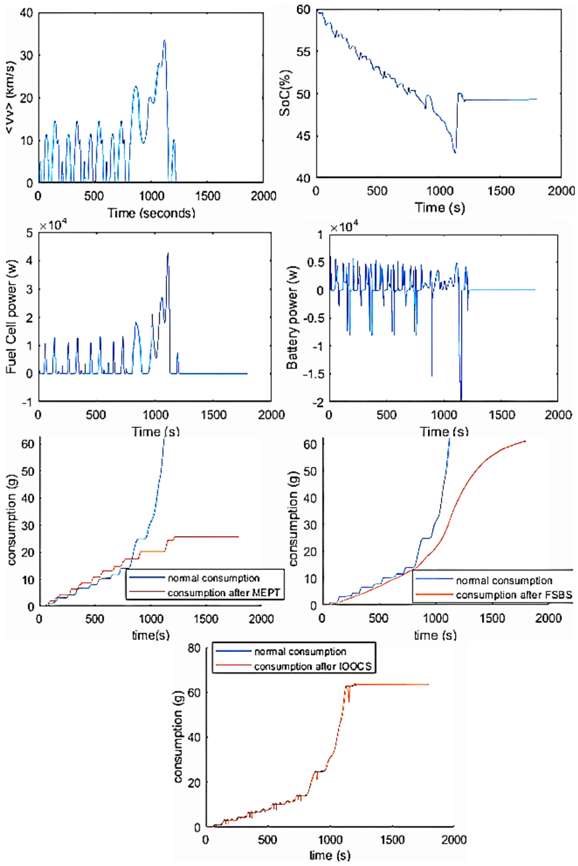

Figure 6. The results of the NEDC driving cycle

Through the analysis of the results given by the different diagrams obtained in the simulation of the three methods chosen through the different driving cycles, the following emerges:

- A significant stabilization of the power spectrum provided by the fuel cell and that of the battery in the three driving cycles due to a good complementary combination between the two energy sources in this model.
- A marked improvement in the economy of hydrogen and consequently of energy in the hybrid vehicle as shown by the results given in the Table 1.
- FBS management strategy, despite the delay at the starting phase, gave good results compared to normal and therefore considered the best optimal method with a saving rate in hydrogen consumption of around -30% almost in the three cycles, followed by MEPT with -12% almost and IOOCS comes at the last place with the lowest yield rate.
- The IOOCS management energy strategy is limited in repetitive peaks in reduction concerning the consumption of hydrogen during the three cycles, which participates in decreasing the effectiveness of this method that remains limited in terms of optimization compared to the others methods studied.

Table 1. Table representing the consumption values using different management energy methods

Strategic management energy method		Driver Cycle NEDS Characteristic points			WLTP Characteristic points			FTP Characteristic points		
		In 6OO s	In 1200 s	mean	In 9OO s	In 1800 s	mean	In 6OO s	In 1200 s	mean
FSBS (g)	Before	10.3	63.5	19.1605	31.184	162.152	37.3012	34.2	51.32	27.1983
	After	9.2	39.1	13.7682	20.2291	106.918	24.3598	24.15	46.23	19.9434
	Difference	-1.1	24.4	-5.3923	-10.955	-55.234	-12.9414	-10.05	-5.09	-7.2549
MEPT (g)	Before	10.3	63.5	19.1605	31.184	16.152	37.3012	34.5	51.32	27.1983
	After	13.02	24.22	16.2722	43.7679	80.4156	36.4438	25.4	52.5	22.0291
	Difference	2.72	-39.28	-2.8883	12.584	-81.736	-0.8574	-9.1	1.18	-5.1692
IOOCS(g)	Before	10.3	63.5	19.1605	31.184	162.152	37.3012	34.16	51.32	27.1983
	After	15.2	68.1	19.8683	11.9	160.3	36.8519	38.2	53.7	27.0601
	Difference	4.9	4.6	0.7078	-19.284	-1.852	-0.4493	4.04	2.38	-0.1382

4. CONCLUSION

This paper combined new ideas about the hybrid system with PEMFC as its principal energy source in order to create a new approach that aims to optimize energy management systems (EMS). The main goal is to engage LiB and primary sources to form a more effective government approach. New concepts regarding the equivalent consumption minimization strategy (ECMS) were developed with a view to improve the overall performance. As demonstrated by simulation's results on MATLAB/Simulink, the FBS energy management approach proved its effectiveness, reducing hydrogen consumption by a third compared to the other two approaches, MEPT and IOOS, which were shown to be less important Optimization. Furthermore, combinations between these simultaneously investigated methods were considered and studied, however, the results were not very significant in terms of achieved optimization rates. For that reason, the study was limited to developing each method separately.

A DC/DC buck converter has been used with an FC emulator for several tests. They all showed that it had good results, as well as genuine FC that performs the same function and lower costs. The voltage and current adjustments are performed by the source. With a high degree of efficiency, multiple objectives are achieved with energy management techniques that aim to Minimize reliance on hydrogen as a resource. Future research and experiments need to keep this in mind as the most appropriate option in ensuring greater autonomy and rational use of clean energies.

REFERENCES

[1] P. Thounthong, S. Raël, and B. Davat, "Test of a PEM fuel cell with low voltage static converter," *Journal of Power Sources*, vol. 153, no. 1, pp. 145–150, 2006, doi: 10.1016/j.jpowsour.2005.01.025.

[2] P. Thounthong, B. Davat, S. Raël, and P. Sethakul, "Fuel cell high-power applications," *IEEE Industrial Electronics Magazine*, vol. 3, no. 1, pp. 32–46, 2009, doi: 10.1109/MIE.2008.930365.

[3] W. Schmittinger and A. Vahidi, "A review of the main parameters influencing long-term performance and durability of PEM fuel cells," *Journal of Power Sources*, vol. 180, no. 1, pp. 1–14, 2008, doi: 10.1016/j.jpowsour.2008.01.070.

[4] F. Savoye, P. Venet, M. Millet, and J. Groot, "Impact of periodic current pulses on Li-ion battery performance," *IEEE Transactions on Industrial Electronics*, vol. 59, no. 9, pp. 3481–3488, 2012, doi: 10.1109/TIE.2011.2172172.

[5] K. M. Tsang, W. L. Chan, Y. K. Wong, and L. Sun, "Lithium-ion battery models for computer simulation," *2010 IEEE International Conference on Automation and Logistics, ICAL 2010*, pp. 98–102, 2010, doi: 10.1109/ICAL.2010.5585392.

[6] P. García, J. P. Torreglosa, L. M. Fernández, and F. Jurado, "Viability study of a FC-battery-SC tramway controlled by equivalent consumption minimization strategy," *International Journal of Hydrogen Energy*, vol. 37, no. 11, pp. 9368–9382, 2012, doi: 10.1016/j.ijhydene.2012.02.184.

[7] Z. Amjadi and S. S. Williamson, "Power-electronics-based solutions for plug-in hybrid electric vehicle energy storage and management systems," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 2, pp. 608–616, 2010, doi: 10.1109/TIE.2009.2032195.

[8] W. Jiang and B. Fahimi, "Active current sharing and source management in fuel cellbattery hybrid power system," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 2, pp. 752–761, 2010, doi: 10.1109/TIE.2009.2027249.

[9] P. Garcia, L. M. Fernandez, C. A. Garcia, and F. Jurado, "Energy management system of fuel-cell-battery hybrid tramway," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 12, pp. 4013–4023, 2010, doi: 10.1109/TIE.2009.2034173.

[10] J. H. Jung, Y. K. Lee, J. H. Joo, and H. G. Kim, "Power control strategy for fuel cell hybrid electric vehicles," *SAE Technical Papers*, 2003, doi: 10.4271/2003-01-1136.

[11] Y. Shuang, Z. Junzhi, and W. Lifang, "Power management strategy with regenerative braking for fuel cell hybrid electric vehicle," *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, 2009, doi: 10.1109/APPEEC.2009.4918610.

[12] A. Fadel and B. Zhou, "An experimental and analytical comparison study of power management methodologies of fuel cell-battery hybrid vehicles," *Journal of Power Sources*, vol. 196, no. 6, pp. 3271–3279, 2011, doi: 10.1016/j.jpowsour.2010.11.114.

[13] K. Min-Joong and P. Huei, "Power management and design optimization of fuel cell/battery hybrid vehicles," *Journal of Power Sources*, vol. 165, no. 2, pp. 819–832, 2007, [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378775306025523.

[14] C. Y. Li and G. P. Liu, "Optimal fuzzy power control and management of fuel cell/battery hybrid vehicles," *Journal of Power Sources*, vol. 192, no. 2, pp. 525–533, 2009, doi: 10.1016/j.jpowsour.2009.03.007.

[15] R. Prasad and R. Prasath, "Performance Analysis of Fuel Cell to Power an Electric Vehicle Using Matlab," *SSRN Electronic Journal*, 2022, doi: 10.2139/ssrn.3993598.

[16] V. Paladini, T. Donateo, A. de Risi, and D. Laforgia, "Control strategy optimization of a fuel-cell electric vehicle," *Journal of Fuel Cell Science and Technology*, vol. 5, no. 2, 2008, doi: 10.1115/1.2784311.

[17] M. S. A. Chowdhury, K. A. Al Mamun, and A. M. Rahman, "Modelling and simulation of power system of battery, solar and fuel cell powered Hybrid Electric vehicle," *2016 3rd International Conference on Electrical Engineering and Information and Communication Technology, iCEEiCT 2016*, 2017, doi: 10.1109/CEEICT.2016.7873126.

[18] M. N. Sid, K. Marouani, M. Becherif, and H. Alloui, "Optimal energy management control scheme for fuel cell hybrid vehicle," *2014 22nd Mediterranean Conference on Control and Automation, MED 2014*, pp. 716–721, 2014, doi: 10.1109/MED.2014.6961458.

[19] N. Sulaiman, M. A. Hannan, A. Mohamed, E. H. Majlan, and W. R. Wan Daud, "A review on energy management system for fuel cell hybrid electric vehicle: Issues and challenges," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 802–814, 2015, doi: 10.1016/j.rser.2015.07.132.

[20] R. Dosthosseini, A. Z. Kouzani, and F. Sheikholeslam, "Direct method for optimal power management in hybrid electric vehicles," *International Journal of Automotive Technology*, vol. 12, no. 6, pp. 943–950, 2011, doi: 10.1007/s12239-011-0107-8.

[21] J. Snoussi, S. Ben Elghali, M. Benbouzid, and M. F. Mimouni, "Optimal sizing of energy storage systems using frequency-separation-based energy management for fuel cell hybrid electric vehicles," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 10, pp. 9337–9346, 2018, doi: 10.1109/TVT.2018.2863185.

[22] J. Snoussi, S. Ben Elghali, M. Benbouzid, and M. F. Mimouni, "Auto-adaptive filtering-based energy management strategy for fuel cell hybrid electric vehicles," *Energies*, vol. 11, no. 8, 2018, doi: 10.3390/en11082118.

[23] A. Florescu, S. Bacha, I. Munteanu, A. I. Bratcu, and A. Rumeau, "Adaptive frequency-separation-based energy management system for electric vehicles," *Journal of Power Sources*, vol. 280, pp. 410–421, 2015, doi: 10.1016/j.jpowsour.2015.01.117.

[24] D. Feroldi, M. Serra, and J. Riera, "Energy Management Strategies based on efficiency map for Fuel Cell Hybrid Vehicles," *Journal of Power Sources*, vol. 190, no. 2, pp. 387–401, 2009, doi: 10.1016/j.jpowsour.2009.01.040.

[25] C. H. Zheng, C. E. Oh, Y. I. Park, and S. W. Cha, "Fuel economy evaluation of fuel cell hybrid vehicles based on equivalent fuel consumption," *International Journal of Hydrogen Energy*, vol. 37, no. 2, pp. 1790–1796, 2012, doi: 10.1016/j.ijhydene.2011.09.147.

[26] P. R. Akula, L. Jandhyala, F. Herb, and A. Narayana, "Development of energy management strategies and analysis with standard drive cycles for fuel cell electric vehicles," *SAE Technical Papers*, vol. 9, 2012, doi: 10.4271/2012-01-1609.

BIOGRAPHIES OF AUTHORS

Rachid Touileb received the M.S. degree in electrical engineering from Mohammadia School of Engineering, Electrical Engineering Department, Mohammed V University in 2018. He is actively pursuing a Ph.D in electrical energy and control at Mohammadia School of Engineering (EMI) Mohammed V University, Rabat, Morocco. His research focuses on optimization of a hybrid vehicle. He can be contacted at email: touilebrachid1@gmail.com.

Ahmed Abbou received the B.E. degree from ENSET in Rabat, the M.E. degree from Mohammed V University in Rabat and the Ph.D. degree from Mohammed V University in Rabat, in 2000, 2005 and 2009, respectively, all in electrical engineering. Since 2009, he has been working at Mohammadia School of engineers, Mohammed V University in Rabat, Department of electric Power Engineering, where he is a full Professor of Power Electronics and Electric drives. He published numerous papers in scientific international journals and conferences proceedings. His current research interests include induction machine control systems, self-excited induction generator, power electronics, sensorless drives for AC machines and renewable energy (PV and wind energy). He can be contacted at email: abbou@emi.ac.ma.