# Assessment of new hydrogen fuel cell technology in Electrical vehicles application and how it would improve the EV's performance

Yueyang Wu *, Yuwei Yang

University of British Columbia, Vancouver, BC, Canada

* Corresponding author Email: yueyang2@student.ubc.ca

**Abstract.** In light of climate change and air pollution, this paper addresses the urgent issue of sustainable transportation. The potential of Fuel Cell Hybrid Vehicles (FCHVs) utilizing Proton Exchange Membrane (PEM) technology is investigated, focusing on the reduction of greenhouse gas emissions by utilizing hydrogen as an energy carrier. Analyzing the intricate interplay between FCHV control systems and overall efficiency, we explore diverse Energy Management Systems (EMS) strategies' impacts on fuel cell degradation, battery performance, and cost. Through a comprehensive literature review, our research underscores FCHVs' pivotal role in achieving sustainability goals while navigating the intricate landscape of technology, control strategies, efficiency, and environmental imperatives. We also evaluate its social, economic, and ecological benefits compared to traditional vehicles. At last, we address specific gap questions which could be studied in the future.

**Keywords:** Power Provision, Electrical Vehicle (EV), EV Charging technology, EV infrastructure, Proton Exchange Membrane (PEM).

## 1. Introduction

Climate change has gradually become the most concerning sustainable problem in our current human society. 73% of current global air pollution comes from energy generation. Transportation is one of the sections that significantly relies on energy generation. The implementation of decarbonization in transportation is essential. According to Luciani and Tonoli, until 2022, fossil fuels still occupy the most market in the global vehicle market [1]. Despite the surging numbers of electric vehicles in the current transportation industry, the industry development and expansion are still not enough for SDG goals. So far, electric vehicles have different categories. For instance, hydrogen, fuel cell, and PEM are all available for powering electric vehicles. In this study, we established a study to review a new type of electric vehicle, which is a Fuel cell hybrid vehicle (FCHV) [1]. Nowadays, many studies have focused on the benefits and possibilities of replacing diesel-fuel and gasoline vehicles with electric vehicles [2, 3]. However, fewer studies focused on how fuel-cell hybrid vehicles and their advanced fuel technology could improve an electric vehicle's infrastructure efficiency and potentially increase performance. Therefore, we would like to study a hydrogen fuel-cell technology that significantly improves vehicle performance and combine different study cases to evaluate the feasibility of this technology.

FCHV vehicles' key technology would be the PEM fuel cell in the engine [1]. Implementing such vehicles has several benefits for future sustainability goals. To minimize greenhouse gas emissions, using hydrogen to replace fossil fuels would be one of the most significant effects [1]. As a relatively new technology, Fuel cell hybrid vehicles still demand full evaluations over different control systems.

After all, to approach a sustainable transportation industry, decarbonization and pollution reduction are one of the most urgent missions in our decade. Many developed countries like Switzerland and Canada have started their energy transition progress [4, 5]. Recently, Switzerland published its renewable energy vehicle expectation, which states that they are about to eliminate traditional fossil fuel vehicles on the market by 2050 [5]. Fuel cell vehicles (FCV) as one the most burgeoning transportation tools, their controlling system deserves a more precise evaluation.

To demonstrate the current FCHV industrial level in this study, case studies of industrial applications are undertaken. The effectiveness and analysis of several "rule-based control strategies" are done [1]. The efficiency of the various methods is assessed with respect to a steady battery state of charge. The efficacy of three different control strategies—constant power, baseline mode-based, and ideal mode-based—is evaluated in specific [6].

## 2. Working Mechanism of Hybrid

Fuel cells (FC) are attractive power sources for applications such as distributed power generation systems and EVs due to their cleanliness, efficiency and high reliability [7]. Working with energy storage systems on the basis of fuel cells is very appropriate, and the hybrid power demonstrated has very many advantages: for example, the demand for transient power is effectively increased and can be done to optimize the efficiency of the vehicle. There are many forms of fuel cells, but the hydrogen-based proton exchange membrane fuel cell (PEMFC) does not require high temperatures, is lightweight, is not very large, and has a higher conversion efficiency, generally 40%-60% [7]. It also has sound noise reduction and significant noise emission capability [8,9]. So PEMFC has also become the first choice for EVs.

Nieto et al. showed that the CO concentration of the PEMFC was significantly insufficient in reaching the transient response to its concentration [10]. In this regard, Rullo et al. argued that the inclusion of a battery pack and supercapacitors into the design of an enhanced base control structure with PFC on the BPS can be effective in improving the vehicle's efficiency problems [11]. The BPS is a system modelled under complex and ever-changing conditions [11]. Its energy system uses various components such as solar energy, batteries, and chemical reactions to interact with each other in order to maximize the use of renewable resources to meet the energy demand [11]. For hydrogen conversion, the system uses an ethanol steam-reforming piston flow reactor. For the carbon monoxide preferential oxidation (CO-PrOx) reactor, the CO is converted to $CO_2$ [11].

## 3. Duration and lifetime

Due to the advantages of all aspects of fuel cell hybrid systems, their practicality and diffusion are increasing significantly. However, their service life and duration have been affected due to load variations. Many research institutes and companies are trying to make changes to this problem, and Goh et al. found that energy management strategies (EMS) can help a lot with the lifetime problem [12]. There are two types of EMS: rule-based and optimization-based, both with their own advantages and disadvantages. Through the study of several articles, it was found that rule-based EMS such as finite state machines, power tracking, and fuzzy logic control have common advantages and disadvantages. One of the advantages is that by comparing multiple sources, it is found to be very reliable and has a very high likelihood of being able to be implemented. However, the disadvantages are also obvious, that is, the efficiency problem can not be guaranteed, and there is no way to achieve a specific guarantee for the life of the more complex cases [13]. In contrast, optimization-based EMS is rated higher due to the significant results of optimization. This strategy continuously surveys and adjusts the parameters to minimize energy consumption and lifetime. It also dramatically improves the satisfaction of all parties in terms of cost [13].

## 4. Controlling systems/management systems & Efficiency

Hybrid fuel cell "requires highly complex management systems (EMS)" [6]. An unqualified management system might result in low performing efficiency, raising the degradation level of the fuel cell. Consequently, such problems might cause the engine's performance to depreciate, ultimately lowering the benefits and functions of H2 utilization [6]. However, due to the distinguished engine design in the market, the categorization and assessment of various management systems or logic systems are often unstandardized. Luca et al. introduced multiple management systems across the market and modelled their performances with a quantifiable standard [6]. According to the study, numerous quantitative metrics are recommended for such an evaluation. Besides the famous "charging sustaining ability" topic, hydrogen as the primary fuel, its consumption is an essential metric. A system which degrades more Hydrogen naturally has a lower efficiency. Fuel cell longevity is another factor that plays a role in influencing the system's functioning. In fact, researchers used a modelling framework run by MATLAB/Simulink, and they concluded that despite certain studies claiming that reducing Hydrogen consumption may allow EMSs to perform well, there are also risks to reducing the fuel cell duration [6].

Several factors play critical roles in influencing hybridization. High efficiency is one of the most convincing reasons to replace traditional fossil fuel vehicles with fuel cell ones. According to researchers, fuel cell efficiency is at the largest under a steady load, which could reach 95% to 98% [6]. Meanwhile, hybridization can be split into passive or active hybridization. Fig. 1 shows the two diverse systems accurately. The fuel cell voltage is often transferred from the active systems to the battery system via a DC/DC converter. Compared to passive systems, which just link the cell and battery parallelly. According to researchers who focused on active systems, such systems allow the management systems to be more flexible and independent of operational voltage.

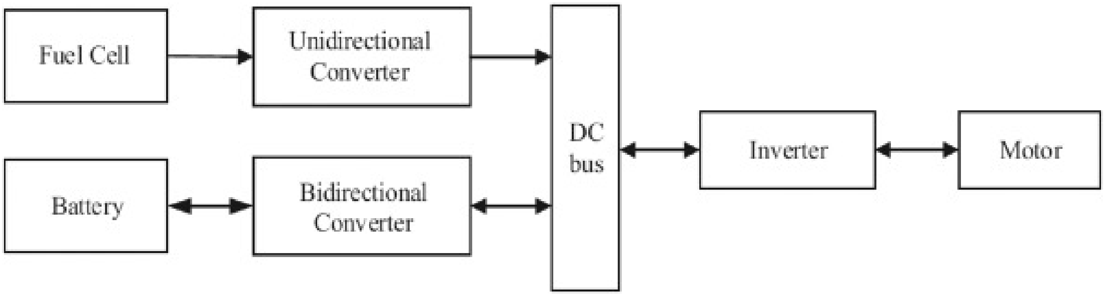


**Figure 1.** The comparison of the active and passive systems of hybridization [6]

## 5. Analysis of cost for Energy Management Systems (EMS)

Fuel cells and battery packs degrade at different rates depending on the Energy Management Systems (EMS) used. According to the explanation in the section devoted to the battery degradation model, there are four main working conditions that can cause fuel cell degradation to occur more quickly: changes in load, stopping and starting operation, idling, and even high-power operation [14,15]. Reactive Load Prioritization (RLP) exhibits the least detrimental effects on fuel cell degradation over the course of a single driving cycle, with a total degradation expenditure of 0.028 dollars related to the high-power operations and stop/start occurrences [6]. However, because of the relatively passive behaviour of the fuel cell under RLP EMS, it registers the second-highest expense in battery degeneration at \$ 0.136. The optimized Fuzzy Logic Controller (FLC) demonstrates commendable performance in terms of fuel cell degradation, incurring a costing of \$ 0.65 and reducing \$ 4.05 when juxtaposed with the standard FLC [6]. This reduction primarily stems from diminished expenses ensuing from load variations, realized by augmenting the width of output membership functions. Due to the fuel cell's more passive nature, the optimization marginally accelerates battery aging, but this is balanced by the significantly decreased costs associated with fuel cell breakdown [6,7]. Therefore, the EMS system might be significant for full-cell functioning [6].

## 6. Prospect Analysis of EVs and conventional gasoline vehicles

There are many essential differences between electric cars and traditional gasoline cars, and a comparative analysis of their prospects is necessary. First of all, for the internal combustion engine internal maintenance needs to be carried out for a long time to prevent wear and tear caused by excessive friction. The electric car has a clear advantage in this regard because, without an internal combustion engine, it does not require frequent oil changes, which is a considerable savings in terms of money spent on car maintenance. Secondly, electric cars have a very positive impact on the environment. Its harmful air emissions are very much less compared to traditional gasoline cars. Although they are not entirely environmentally friendly, they are exemplary. In terms of safety, electric vehicles run on batteries, and in the event of an emergency, when the airbag deploys it will automatically cut off the power, which reduces the risk of further harm. But the biggest problem with electric cars is how to promote them in some countries where charging piles are not widespread. Gasoline filling stations are few in number and underdeveloped compared to charging piles. In conclusion, electric vehicles offer environmental benefits, energy efficiency and potentially lower operating costs compared to conventional gasoline vehicles [16]. At the same time, however, relevant R&D departments also need to pay attention to the development of infrastructure for their charging and other influencing factors.

## 7. Conclusion

In conclusion, the combined system of fuel cell system presents a compelling avenue towards clean energy adoption, underscored by its inherent cleanliness and commendable efficiency. This transformative vehicle technology revolutionizes vehicle utilization, enhancing overall performance and efficiency and exhibits an acceptable cost profile. The feasibility of chemical fuel implementation is underscored by its alignment with key imperatives, including accessibility, and a confluence of societal and economic advantages. However, future research endeavours must address existing gaps in understanding. Developing a robust application model is imperative to delineate the precise parameters governing the integration of chemical fuel technology within vehicular systems. Additionally, avenues for enhancing the technology itself warrant exploration, probing avenues for refinement and augmentation. Lastly, the challenge of improving public accessibility to this emerging technology emerges as a pertinent issue, necessitating innovative strategies for widespread adoption. As the trajectory of clean fuel in the context of EVs continues to evolve, these areas of inquiry offer promising avenues for sustained progress and innovation.

## Authors Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

## References

[1] Luciani, S., & Tonoli, A. Control strategy assessment for improving PEM fuel cell system efficiency in fuel cell hybrid vehicles. Energies, 2022, 15 (6).

[2] Lim, K., Kim, J. J., & Lee, J. Forecasting the future scale of vehicle to grid technology for electric vehicles and its economic value as future electric energy source: The case of South Korea. Energy & Environment, 2020, 31 (8), 1350 - 1366.

[3] Kirsanovs, V., Barisa, A., & Safronova, A. Cost-benefit assessment of electric vehicle vs internal combustion engine in Latvia. In 2020 IEEE 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), 2020, November, pp. 1 - 4.

[4] Neofytou, H., Nikas, A., & Doukas, H. Sustainable energy transition readiness: A multicriteria assessment index. Renewable and Sustainable Energy Reviews, 2020, 131, 109988.

[5] Kannan, R., Panos, E., Hirschberg, S., & Kober, T. A net-zero Swiss energy system by 2050: Technological and policy options for the transition of the transportation sector. Futures & Foresight Science, 2020, 4 (3-4).

[6] Luca, R., Whiteley, M., Neville, T., Shearing, P. R., & Brett, D. J. Comparative study of energy management systems for a hybrid fuel cell electric vehicle-A novel mutative fuzzy logic controller to prolong fuel cell lifetime. International Journal of Hydrogen Energy, 2022, 47 (57): 24042 - 24058.

[7] K. Jin, X. Ruan, M. Yang and M. Xu, "A Hybrid Fuel Cell Power System," in IEEE Transactions on Industrial Electronics, 2009, 56 (4): 1212 - 1222.

[8] F. Zenith, S. Skogestad. Control of the mass and energy dynamics of polybenzimidazole-membrane fuel cells. Journal of Process Control, 2009, 19 (3): 415 - 432.

[9] C. Woo, J. Benziger, PEM fuel cell current regulation by fuel feed control. Chemical Engineering Science, 2007, 62 (4): 957 - 968.

[10] L. Nieto Degliuomini, D. Zumoffen, M. Basualdo Plant-wide control design for fuel processor system with PEMFC. International Journal of Hydrogen Energy, 2012, 37 (19): 14801 - 14811.

[11] Degliuomini, L. N., Cunningham, M., Ferreyra, F., Luppi, P. A., & Basualdo, M. S. Energy management of a hybrid-controlled process with renewable sources. Computer Aided Chemical Engineering, 2014, 33: 1141 – 1146.

[12] G. D. Goh et al. Additive manufacturing in unmanned aerial vehicles (UAVs): Challenges and potential. Aerospace Science and Technology, 2017, 63:140 - 151.

[13] Ma, R., Song, J., Zhang, Y., Zhang, H., & Yuan, M. Lifetime-Optimized energy management strategy for fuel cell unmanned aircraft vehicle hybrid power system. IEEE, 2023, 70 (9): 9046 - 9056.

[14] Hossain Lipu, M. S., Miah, M. S., Ansari, S., Wali, S. B., Jamal, T., Elavarasan, R. M., ... & Tan, N. M. Smart Battery Management Technology in Electric Vehicle Applications: Analytical and Technical Assessment toward Emerging Future Directions. Batteries, 2022, 8 (11), 219.

[15] Kumar, M., Panda, K. P., Naayagi, R. T., Thakur, R., & Panda, G. Comprehensive Review of Electric Vehicle Technology and Its Impacts: Detailed Investigation of Charging Infrastructure, Power Management, and Control Techniques. Applied Sciences, 2023, 13 (15): 8919.

[16] Hayes, J. G., & Goodarzi, G. A. Electric powertrain: Energy systems, power electronics and drives for hybrid, electric and fuel cell vehicles. Wiely, 2018.