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ENERGY MANAGEMENT STRATEGY FOR HYDROGEN FUEL CELL ELECTRIC VEHICLES

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Abstract:
Energy Management Strategies (EMS) are crucial in influencing the performance, efficiency, and durability of hybrid cars. The EMS regulates the working conditions of essential powertrain components, hence affecting almost all facets of a vehicle's functioning, including energy consumption, component wear, drivability, and performance. Consequently, designing the EMS for hybrid electric cars is a complicated task that necessitates balancing various, often competing, goals. These include the reduction of fuel consumption, the enhancement of the driving experience, the mitigation of mechanical and electrical wear on components, and the improvement of overall performance. In Fuel Cell Hybrid Electric Vehicles (FCHEVs), the Energy Management System (EMS) is of paramount importance, owing to the intricate integration of fuel cells and batteries, as well as the heightened sensitivity of fuel cells to operational circumstances and deterioration. This work presents a notable development in fuel cell vehicle management by including fuel cell deterioration into the primary optimization goals of the Energy Management System (EMS). This facilitates improved long-term economic performance and fosters the sustainable and feasible deployment of FCHEVs. The results demonstrate that a well-designed EMS may significantly prolong a fuel cell's lifespan while highlighting the capacity for strategic design choices to lower overall ownership costs. As FCHEVs increasingly emerge as an alternative to internal combustion and battery-electric cars, techniques such as the one described herein will be crucial in addressing the persisting technological and economic problems.

Keywords: Fuel cell electric vehicle; DC/DC converter topologies; energy management strategy.

I. INTRODUCTION

In order to continue using fossil fuels, which means 80% of the world's energy demand, there are two main problems [1]. The first problem is the limited amount of fossil fuel, and sooner or later these sources will be consumed. Estimates of petroleum companies show that by 2023 there will be a peak in the exploitation of fossil fuels, petrol and natural gas, and then they will start to decline [2].

The second and most important problem is that fossil fuels cause serious environmental problems such as: global warming, acid rain, climate change, pollution, ozone depletion, etc. Estimates show that the worldwide destruction of the environment costs about $5 trillion annually [3].

The solution proposed for the two global problems first appeared in 1970 as the "Hydrogen energy system" [4]. In the last decade through research and development work in universities and laboratories of research institutes around the world shows that hydrogen is an excellent source of energy with many unique properties. It is the cleanest and most efficient fuel [5].

The unique property of hydrogen in electrochemical processes is that it can be converted into electricity in the fuel cell system which makes it much more efficient than the conversion of conventional fuels into mechanical energy [6]. This unique property of hydrogen has led to the manufacture of hydrogen fuel cells and makes them a very good choice for automotive companies [7].

The alternative to fossil fuels found by car manufacturers for fueling vehicles is represented by other energy sources, such as: battery systems, ultracapacitors or fuel cells. Electric Vehicles (EVs) and Fuel Cell Electric

Vehicles (FCEVs) are the most viable solutions for reducing Greenhouse Gases (GHG) and other harmful gases for the environment. Although EVs and FCEVs can reduce emissions to a certain value, they do not reduce them to absolute zero [8].

Thus, the renewable energy transport infrastructure allows FCEVs to become a preferable choice, because they attract great attention in the road and rail transport sector (and not only), without using fossil fuels [9]. FCEVs and FCHEVs use a combination of Fuel Cells (FC), and batteries (B) or/and Ultracapacitors (UC) [10]. The research stages for FCHEVs include the development of vehicles and the improvement of their efficiency. Beside the fuel cell system, they use the battery and/or ultracapacitor pack as a complementary power source to provide the required power on the DC bus. The topologies of FCEVs are described in detail in [11]. To increase the power density and to meet the demand for load power, it is necessary to integrate an energy management system. The energy management strategy of FCEVs is based on many important control techniques [12] such as finite state machine management strategies [13], grey wolf optimizer [14], model predictive control [15,16], fuzzy logic control [17,18], genetic algorithms [19,20], hierarchical prediction [21,22] as well as other control techniques developed so far for the energy management system.

This paper aims to update and introduce the new technologies regarding the FCEVs topology and Energy Management Strategies (EMS). In this regard, the paper will analyze recent research in the field, based on selected reference papers (87% published from 2018 to date), helping potential researchers and developers to get a more detailed picture of FCEV technologies.

II. ENERGIES CONTROLLING TECHNIQUES

The CD approach, which is based on the notion that the car would be recharged while stationary, will allow the battery state of charge to gradually drop over time. The ACS technique, however, will strive to maintain a reasonably stable state of charge (SoC) in the batteries throughout operation, since the battery is not designed to be recharged while the vehicle is idle. These aims may be attained using very straightforward procedures; one such example is the "thermostatic" approach. This method functions similarly to how it performs at its best (hence its name). The battery is recharged when it drops below a certain threshold after being allowed to discharge. Charging stops and the battery is allowed to drain once again when the state of charge (SoC) reaches a secondary increased threshold. Depending on the vehicle's design, the components' operating characteristics will change under discharge and charging conditions. The internal combustion engine (ICE), for example, may run at max. power via charging & at max. efficiency via discharge, or it may be dormant during discharge and run at its best efficiency while charging. The EMS's choices dictate the operating points of several power train components, significantly impacting the vehicle's overall operational efficiency. An effectively constructed EMS has shown the capacity to enhance fuel efficiency by around 10%-20%. A substantial body of study exists in the literature about the optimization of the EMS. The predominant emphasis of this research is to ice-based hybrid cars, and a significant portion of this work is also applicable to fuel cell vehicles. Nonetheless, certain concerns are peculiar to fuel cells, particularly those associated with the aforementioned challenges. While the EMS cannot directly influence the cost of the stack, enhancing its operational efficiency may allow for a decrease in the size of the fuel cell stack, hence indirectly decreasing costs. Moreover, enhanced efficiency will decrease hydrogen storage needs. The liability of a fuel cell will ultimately rely on its use. Vehicular applications often impose significant stress on fuel cells owing to elevated levels of transient loading. If the EMS is constructed to consider prevalent degradation techniques, then the stack's reliability might be enhanced.

III. CAR MODEL

The first model captures a great deal of information and is a complete forward-facing depiction of the test vehicle. In order to improve the effectiveness of optimization processes, the second model a backward-facing variant has been simplified. A modular strategy has been adopted, concentrating on high-level maintenance of the vehicle model. This has been achieved by characterizing several components using actual data and, where practical, steady-state and quasi-steady-state models and hence maximizing model reduction.

An explanation of the general modeling philosophy used to this project opens this chapter. Both models' overall structure is described, as are the methods for making the complex model simpler. We next outline each component model independently, describing the MicrocabH4's parameters and their component-level validation. The control models are outlined and ready for SDP tuning at the end of the section.

DESIGN BASED ON MODELS (MBD)

When creating modern control algorithms, simulation over extensive testing;

Safety: First and foremost, testing the controller on a desktop computer in a fully simulated setting eliminates the possibility of causing harm to the machinery or putting employees in danger. In addition to evaluating the safety of algorithms before putting any personnel or equipment at risk, this makes it easier to analyze situations that would be too dangerous or expensive to study on a large scale.

Velocity: With the least amount of organizational strain, quick input on design changes may be acquired. This significantly reduces the amount of time needed to troubleshoot the controller code and allows for more frequent testing. This guarantees outstanding consistency while allowing parameter sweeps to be carried out in a much shorter amount of time than thorough testing.

Details: Characteristics that are difficult or impossible to measure on a vehicle are often included in simulation models. If the model is accurate, this enables a more comprehensive examination of the controller's effect than may be possible via full-scale testing.

Repeatability: In the end, simulation replaces experimental gear, which might malfunction or be improperly calibrated. This benefit also suggests that the results are quite repeatable.

IV. SIMULATION & RESULT

The controller derived from the Microcap H4's existing approach) and a controller that was optimized solely for fuel economy. The current design shows that, even when the optimal control method is used, The 1.2 kW fuel cell output is inadequate to sustain the batteries States of Capacity (SoC) throughout standard operations. The outcomes are recalibrated for a 4.8 kW stack characteristic of the latest Microcap H2EV, revealing that the present regulate planning is inadequate for the overall construction. In contrast, the degradation inclusive controllers diminishes the anticipated deterioration by approximately 15% with merely a 4% rise in fuel usage relative to the planning designed solely for fuel effectiveness. This results in an approximate 9% reduction in operational expenditures.

Figure 1 makes it abundantly evident that increasing the fuel cell size will cause much greater degradation from transient loading using the baseline method. This can be attributed to the current control strategy's strong emphasis on reaching a high battery state of charge (SoC).

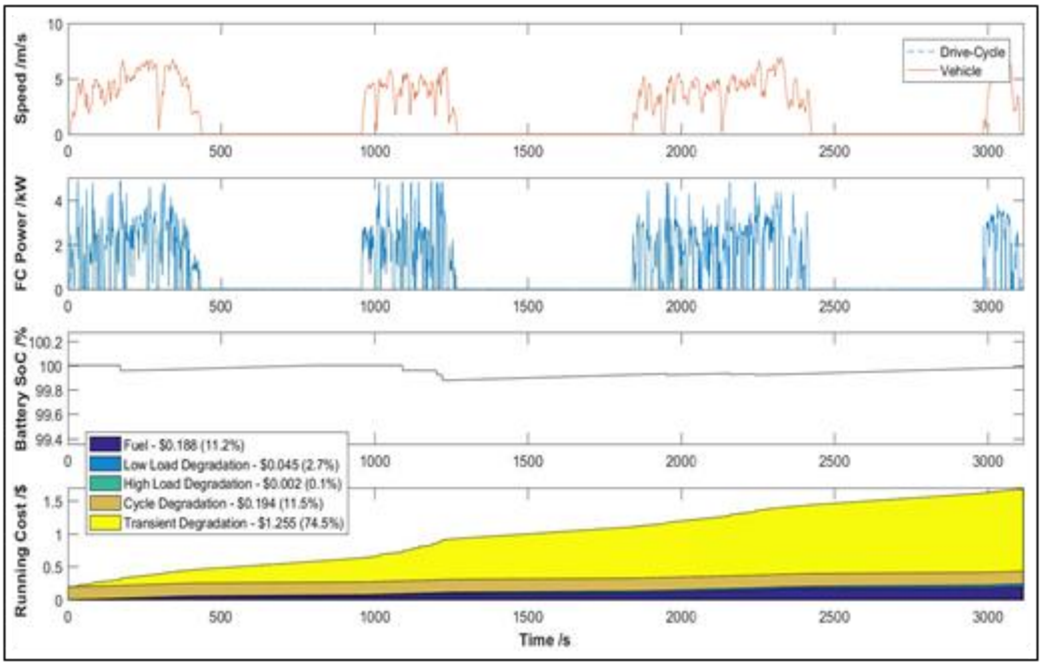

Figure 1: Cumulative Operating Expenses for the Current Microcap Controller (4800W)

The method works similarly to previous implementations, increasing the fuel cell's load when is presented in Figure 2. This suggests that the fuel cell responds to the electrical demand by operating reactively, creating a highly transitory loading pattern.

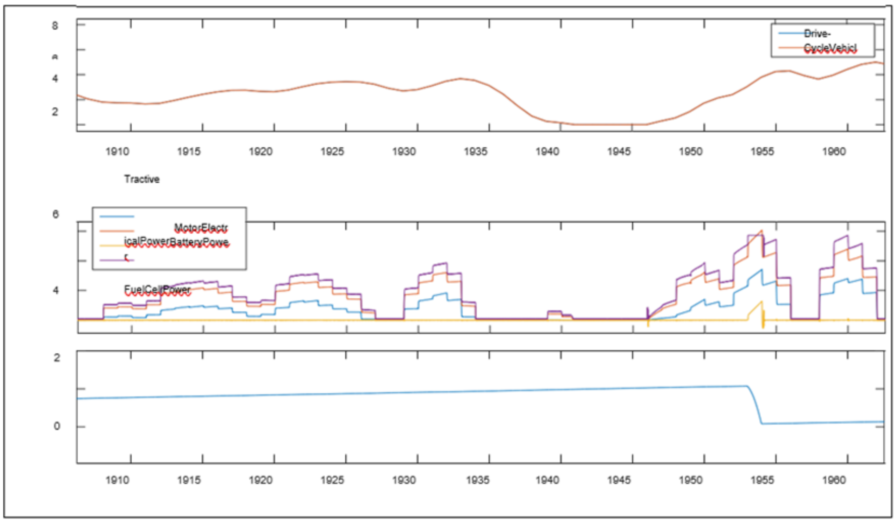

Figure 2: Fundamental Controllers Electricity Managing (4800W)

Whenever efficiency is increased. Additionally, cycle losses in the battery cause just 99% of the energy to be lost. As a result, gasoline consumption drops from 12.5 g/km to 10.5 g/km, a 16% reduction overall. Unfortunately, only around 11% of the total cost of this trip is related to fuel use. With an anticipated length of 139 hours and an overall rise in travel expenditures of around 540%, the varying load.

The results for all 10 assessed itineraries are shown in Table 1. The inclination persists over the whole spectrum. Over all trips, fuel consumption is decreased by 9% to increase dramatically, almost tenfold, lowering the fuel cell's anticipated lifetime from decreased via about 79%, but the degradation from operation at low loading is also increased.

Table 1: Efficiency Overview for the Existing Microcap Controllers (4800W)

No	Duration	Distance	Mean Motor Power	Hydrogen Consumption	Estimated Lifetime	Estimated Range	Total Cost
1	3217s	4.3km	0.66kW	$11.9gkm^{-1}$	140h	50.6km	$1.69
4	3115s	6.0km	0.86kW	$10.5gkm^{-1}$	139h	56.9km	$1.68
12	1546s	4.7km	1.41kW	$11.0gkm^{-1}$	223h	54.6km	$0.62
15	1715s	3.9km	1.05kW	$10.6gkm^{-1}$	110h	56.7km	$1.16
23	1768s	2.8km	0.76kW	$11.5gkm^{-1}$	128h	52.0km	$1.01
32	1283s	2.9km	1.08kW	$11.5gkm^{-1}$	188h	52.2km	$0.55
41	946s	3.2km	1.67kW	$11.5gkm^{-1}$	178h	52.3km	$0.46
51	3411s	5.7km	0.81kW	$11.8gkm^{-1}$	270h	50.9km	$1.04
71	2354s	3.8km	0.76kW	$11.4gkm^{-1}$	334h	52.7km	$0.60
78	2319s	3.1km	0.62kW	$11.4gkm^{-1}$	137h	52.7km	$1.23
Total	**21674s**	**40.2km**	**0.88kW**	$\mathbf{11.3gkm^{-1}}$	**166h**	**53.2km**	**$10.05**

It is evident that the existing technique must be altered spends a large portion of its operating time at full capacity. Because of their high current, fuel cells suffer significant ohmic losses at high loads. The battery pack is no longer used by the EMS to reduce the transient loads that occurs during vehicle duty cycles. Therefore, developing technique that maintains the fuel outcomes linked to the larger fueled-celling while allowing for a greater range in battery state of charge during the cycle is crucial. This might considerably lessen the fuel cell's temporary stress.

V. CONCLUSIONS

The considering the overall requirements of each component, their interaction, and a critical assessment of sophisticated supervisory control techniques. According to the literature review, represent the state of technology due to their popularity and reliable performance. A number of other methods were found, some of which, , merit further research. Yet it was chosen to concentrate on the tried-and-true approach for general hybrid cars and modifies of those methods for a fuel cell vehicles. The chosen areas were chosen to increase the study's scientific value since they were identified as separate areas that needed more research for FCHEVs. While the reduction of degradation prolongs vehicle lifetime, which is also recognized as a major limitation of current. The project encountered a few minor issues. The first problem was the limited amount of data on the Micro cab's use, which made it necessary to investigate methods for improving the quality of the duty cycle. Even while this was very likely, both of these approaches had a special problem in that the vehicle may end up in an unheard-of state.

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