Remodeling of a commercial plug-in battery electric vehicle to a hybrid one with PEM fuel cell

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1. Introduction

Today, most of commercially zero emission vehicles (ZEVs) available are pure electric ones (EVs) powered with batteries (BEV), with the main drawback of their limited range. A very interesting solution is to combine different power sources that can be connected either in serial, parallel, or serial-parallel configurations. This strategy is known as hybridization, and its implementation ensures high values of both energy and specific power [1]. The first hybrid powerplants (HPP) were based on ICEs, achieving a significant reduction in consumption rates. Other solutions are based on hybrid electric architectures (actually ZEVs), powered by batteries (or capacitors) and fuel cells, also extending the original autonomy.

This paper presents the results obtained in the project "*Profitable Small Scale Renewable Energy Systems in Agrifood Industry and Rural Areas: Demonstration in the Wine Sector*" funded by the European Union under the LIFE+ program. A commercial electric car was suitably modified to be powered by a hybrid powertrain based on PEM fuel cell and the original batteries. The ZEV acts at the end-user of the green-hydrogen produced by the water electrolysis using the exceeding electrical energy from three different photovoltaic panel arrays.

2. Description of the electric vehicle platform

2.1 The plug-in electric vehicle

The commercial *ePath-7500* used in this project is a plug-in battery electric vehicle (BEV) electric vehicle. This is an all-wheel drive 4-seat vehicle designed to travel on bumpy and irregular terrain, ideal for agricultural or industrial work tasks. The 7.5 kW 72 V electric motor is powered by a set of 12 gel-type 225 A-h batteries, so the nominal energy stored is 16.2 kWh.

An electric plug placed at the front side of the car is used to recharge the batteries from the electric nertwork. The total recharge time is around 8 hours. The BEV has a tilting load platform at the rear side where the fuel cell system (PEMFC stack, hydrogen storage and supply system, electric, electronic and control devices) is assembled.

2.2 The modified electric vehicle

The commercial BEV was suitably modified to be powered by a hybrid powertrain based on PEM fuel cell and the original gel-type batteries. Several modifications were performed to adapt both the pure electric battery powertrain and its tilting rear load platform to include a commercial PEM fuel cell stack with its corresponding gas storage and supply system and the electronic devices needed for hybridization. Two photos of the modified EV is shown in Fig. 1.

Fig. 1. Photos of the modified electric car with the fuel cell system assembled at the tilting rear load platform

2.3 The PEMFC stack

A commercial H-3000 open-cathode PEMFC stack, manufactured by Horizon, was included as the second power source in the hibrid powerplant (HPP). With a nominal power of 3 kW, it is composed of 72 cells with an active area of 200 cm^2. To prevent the stack from degradation, an optimal current density of 200 mA cm^{-2} has been considered. At this point the stack will generate 40 A at 48 V, corresponding to an operational power of 1,920 W.

The hydrogen to be used by the PEMFC stack of the HPP is stored in four aluminum bottles with a total water volume of 40 l. The hydrogen supply system to the stack, includes, as a novelty, a Venturi-type ejector. This element allows to recirculate passively part of the unreacted hydrogen, and to reintroduce it to the stack with no extra electrical consumption. Another filter is also placed in the recirculation line, in order to collect most of the water dragged by the recirculated gas, which is eventually eliminated from the filter by the purging procedure.

2.4 The PEMFC stack *control system*

To control the stack, a discrete state machine model was developed in LabVIEW [2]. The code was embedded into the microcontroller of a NI roboRIO electronic control unit (ECU) with LINUX realtime operating system. A diagram of the state machine strategy is depicted in Fig. 2. The initial operating mode, START, is just a transient state. Once all parameters are reset, the stack immediately goes into the IDLE state, waiting until the "fuel cell ON" button is pressed, shifting to START FC. If, due to a problem, either the stack can not be turned on or it does not work properly, it will return to the IDLE mode.

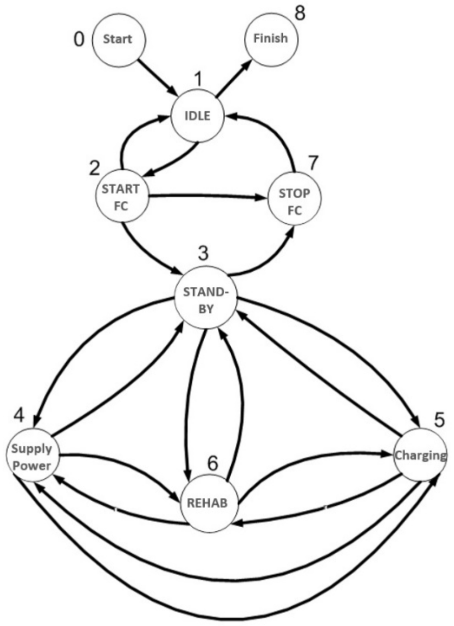

Fig. 2. Diagram of the operating modes of the state machine used to control the stack performance

If the fuel cell is properly turned on, it is moved to STAND-BY mode, where the stack only generates the power consumed by the ancillary systems. Three situations are considered for this operational mode. On the one hand, when the control system detects that the SoC of the gel-type batteries is below 95% and the vehicle operates in a low rate consumption, the stack is switched to CHARGING mode. On the contrary, if the power demanded at the main DC bus increases, it is shifted to SUPPLY POWER state, yielding the 30% of the total power. When the PEMFC stack works properly, it is forced to alternate between STAND-BY and SUPPLY POWER modes. However, if the voltage delivered by the stack for a given current departs a 10% from that established by the embedded polarization curve, it is moved to the rehabilitation state (REHAB). In this case, the purging strategy is activated, and hydrogen pressure is increased to eliminate the water accumulated inside the stack. Usually, the performance of the stack is improved and it is again moved to SUPPLY POWER or CHARGING modes. On the contrary, if after the purges the performance of the stack is not improved, it is sequentially moved to STAND-BY, STOP FC and IDLE states. Finally, it is shifted to the FINISH mode, stopping the hybrid control sequence.

3. Results

Some results obtained at the preliminary tests are presented lines below.

3.1 Electrical consumption of the electric car

In the field tests performed, it was verified that the range of the hybrid vehicle, running continuously in the circuit defined between the two wine cellars of the winery, is 4.94 hours. Therefore, as the time needed for the car to complete a round trip is 8 minutes, the electric car can perform around 37 visits per day with the energy initially stored. Compared to the the original pure BEV, an increase in the range close to 48.5% is achieved with the hybrid power plant. So, the 45.4% of the electrical energy is supplied by the PEMFC stack, and the remaining 54.6% is provided from the energy stored in the gel-type batteries.

3.2 Performance of the hydrogen refuelling system

Result obtained is shown in Fig. 3, where the dashed line represents the pressure at GSS of the hydrogen station, and the continuos one to the GSS of the vehicle. As can be observed, the 4 bottles forming the GSS of the vehicle are fully refilled in less than 1 minute, and the 95% of the hydrogen capacity is refilled in around 30 s. The final pressure of the stored gas is close to 195 bar.

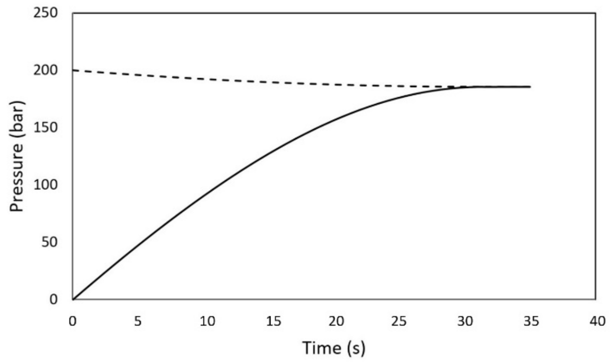

Fig. 3. Time needed to refill the GSS experimentally obtained in field tests

4. Conclusions

A commercial plug-in *ePath-7500* BEV was suitably modified to be powered by a hybrid powertrain including a commercial H-3000 PEMFC stack. The PEMFC system (electric and electronic control, hydrogen storage, and the stack) was assembled at the original tilting rear load platform. As a novelty, the hydrogen supply system includes a Ventury-type ejector that allows the recirculation of part of the unreacted hydrogen form anode sides. Besides, a state machine rule-based control has been developed for the optimal performance of the stack. This strategy prevents the stack from degradation, enlarging its useful lifetime. Finally, preliminary tests have demontrated the the HPP roughly double the vehicle autonomy.

5. Acknowledgements

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6. References

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