# Experimental Validation of Fuel Cell, Battery and Supercapacitor Energy Conversion System for Electric Vehicle applications

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**Abstract.** Due to the increasing air pollution and growing demand for green energy, the most of research is focused on renewable and sustainable energy. In this work, the PEM fuel cell is proposed as a solution to reduce the impact of the internal combustion engines on air pollution. In this paper a PEM fuel cell, battery and supercapacitor energy conversion system is proposed to ensure the energy demand for an electric vehicle is achieved. The storage system consisting of a battery and supercapacitor offers good performance in terms of autonomy and power availability. In this paper, an energy management of the PEM fuel cell electric vehicle has been first simulated in Matlab/Simulink environment and the results are discussed. Second, a Real-time experimental set up is used to test the performance of the proposed PEM fuel cell electric vehicle system. Experimental results have shown that the proposed system is able to satisfy the energy demand of the electric vehicle.

**Keywords:** Fuel Cell, Supercapacitor, Batteries, Electric vehicle.

## 1. Introduction

The combustion engine using fossil fuels is increasingly subject to controversies, due to its undesirable and negative impact on ecology. Moreover, it is not the only source of pollution but it is considered as the last link in a long chain of massive and irreversible destruction of the environment. Feeling an imminent danger, the modern society has introduced the concept of eco-responsibility in all industrial processes to reduce its carbon impact. The electric vehicle (EV) and the hybrid electric vehicle (HEV) constitute some of the solutions to this new eco friendly philosophy.

However, the HEV still uses a combustion engine although in a reduced or exceptional way it does however contribute quite significantly to the carbon impact foot print. The key solution is probably to use a pure electric vehicle (PEV). For this kind of vehicles, we can find two very different concepts. The first is powered by batteries which are, themselves, charged by an external source using fixed and known recharging terminals spread through a given territory. This method is primarily disputed because often the energy available on these charging stations emanate from fossil fuels and non-renewable energies. The second type is relatively less harmful with a reduced carbon

impact and offering more autonomy to vehicles by the virtue of using a fuel cell as a primary source [1, 2].
It is this type of the system that this paper focuses on. In this paper a PEM fuel cell electric vehicle power conversion system has been proposed. The proposed electric vehicle system prototype consists of fuel cell, battery and supercapacitor. The PEM fuel cell electric vehicle is simulated first under Matlab/Simulink and energy management strategy is validated. Real-time setup is used to test the performance of the proposed PEM fuel cell electric vehicle system using Real Time Interface using dspace 1103.
This work is organized as follows: In Section 2, the system's configuration and the modelling of the PEM fuel cell has been presented. In section 3, a numerical simulation of the PEM fuel cell and supercapacitor conversion system has been presented under Matlab/Simulink environment. To validate the proposed system, experimental tests have been obtained and discussed in Section 4. Finally, the conclusions of this work have been provided in Section 5.

## 2. System Description

The proposed topology of the PEM fuel cell electric vehicle is shown in Fig. 1. It includes a PEM fuel cell controlled throughout a boost dc-dc converter, battery that is connected to the dc bus and a supercapacitor ($U_c$) controlled by a buck-boost dc-dc converter. The hybrid storage system offers good performance in terms of autonomy and power availability. In this topology, an energy management of the PEM fuel cell electric vehicle has been considered.

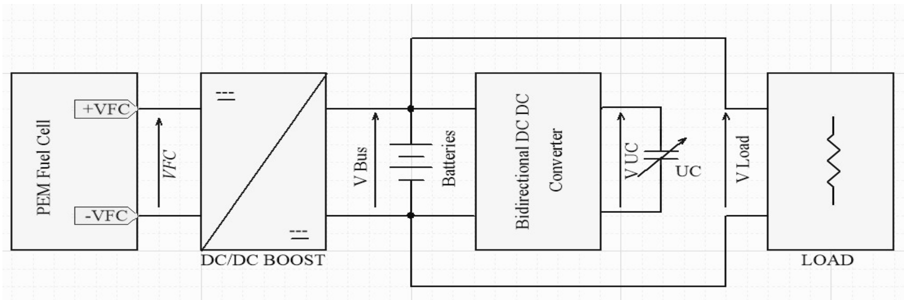



**Fig.1.** PEM fuel cell based EV Topology

## 3. PEM Fuel Cell Modelling

The nature of the fuel cell and the inherent laws that govern it are such that its net voltage is lower than the voltage generated inside. Voltage drops characterize the operation of the PEM fuel cell. These drops are due to the chemical reactions that take place in the PEM fuel cell [3]. The PEM fuel cell model is given by Eq. 1 and Eq. 2:

$$V_{fc}=n_{fc}V_{cell}=n_{fc}(E_{nernst}-V_{act}-V_{ohm}-V_{conc}) \quad (1)$$

$$E_{Nernst}= 1.229 - 8.5\, e^{-4}\,(T_{fc} - 298.5) + 4.308\, e^{-5}\,(Ln(P_{H2}) + (1/2)Ln(P_{O2})) \quad (2)$$

Where, $V_{act}$ is due to delayed activation of Hydrogen molecules; $V_{ohm}$, which in turn is due to the nature of the materials making up the fuel cell, $V_{conc}$ due to the concentration

of the hydrogen during crucial current requirements, $n_{fc}$ and $V_{cell}$ are the number of cells and the cell voltage respectively. $E_{Nernest}$ is the thermodynamic potential of the cell. The $P_{O2}$, $P_{H2}$ and $T_{fc}$ are oxygen and hydrogen partial pressures and cell temperature. The PEM fuel cell characteristic shown in Fig. 2 depends on the gaseous flow at the level of these electrodes and hence depends on the duration of their depletion in gas. In the case of a sudden change in the load current, the electrical transient that manifests itself in a more or less significant voltage drop that will depend not only on the availability of gas and air at the electrodes, but also the speed of the chemical reaction at the origin of electron production, as well as the nature of the materials from which the cell is made up. This transient will end as soon as the throttle pressure is readjusted [4], [5].
The PEM fuel cell V-I and P-I polarization curves are shown in Fig. 2; the fuel cell is supplied with oxidant (oxygen present in the air) at a pressure of 1 bar. In a practical case, a forced ventilation duct is sufficient. For fuel systems without hydrogen regulation, the pressure is mechanically set at 1.5 bars. Elimination of the water and heat produced is carried out through an air flow via the cathode [6], [7].

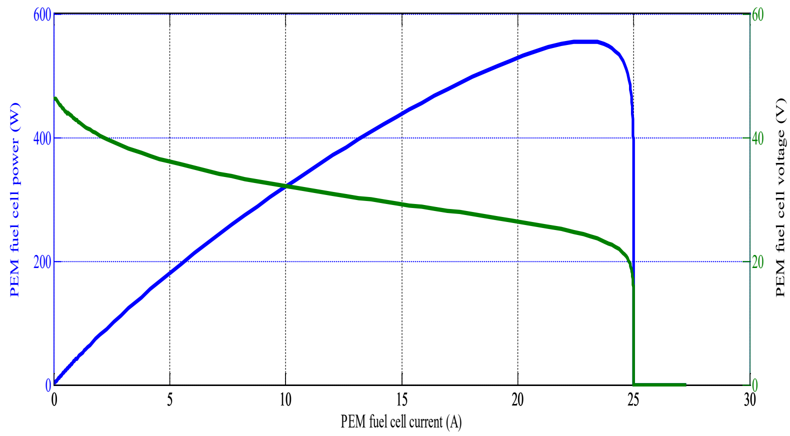



**Fig. 2.** PEM fuel cell V-I and P-I polarization curves

## 4. Simulation tests

The proposed PEM fuel cell electric vehicle is tested under Matlab/Simulink. The Simulink bloc diagram developed in this work is shown in Fig. 3. The PEM fuel cell, battery and supercapcitor models are realized under Powersyst Toolbox of Matlab. The PEM fuel cell is controlled as a main power source and the battery/Supercapacitor as a backup power source. The tests are performed in a variable electric vehicle power load. In addition, the energy management of the whole system is designed to share the PEM fuel cell electric vehicle power demand. The load bloc represents the electric vehicle and the storage batter model. The simulation results shown in Fig. 4, illustrate that the proposed conversion system is able to satisfy the electric vehicle power load.

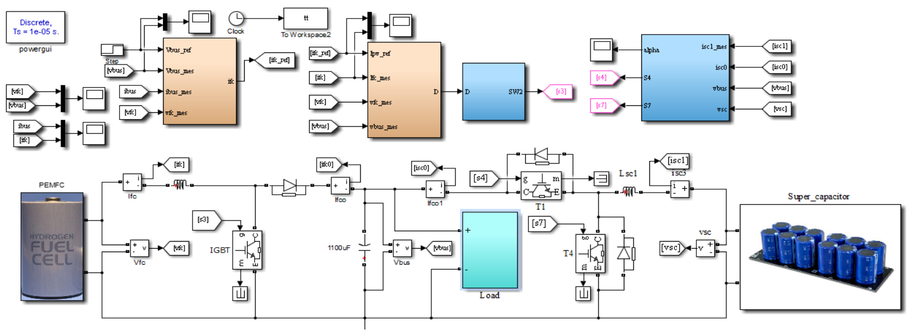


**Fig. 3**. Simulink bloc of the proposed system

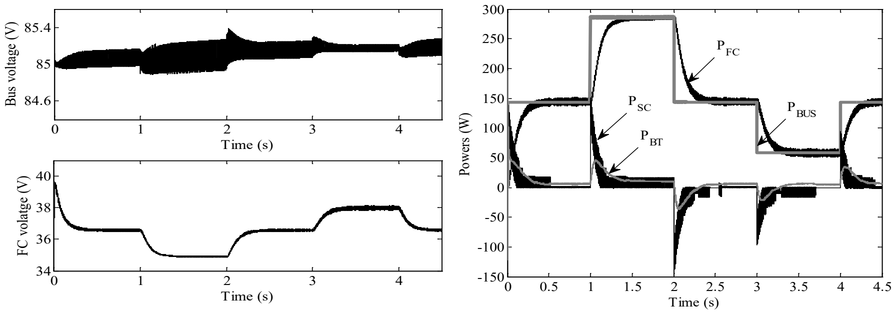



**Fig. 4**. PEM fuel cell Model Simulation Results

## 5. Experimentation and Validation

Real-time experimental part is based on the emulation of the PEM fuel cell. This emulation is realized by a buck dc-dc converter; this converter is controlled to produce the behaviour of the PEM fuel cell. The benefit of this emulation is the possibility to perform the experimental tests without need the real fuel cell, in addition, the input gases pressures and temperature can be changed in this emulator. This PEM fuel cell emulator is associated with a Boost dc-dc converter (see Fig. 5). Figure 6 show the electronic circuit of the PEM fuel cell emulator. The fuel cell emulator system consists of mains power supply of 80 V associated with a dc-dc buck converter controlled by a simple PI regulator and mathematical model of the fuel cell (see Fig. 5). The results given in Fig. 7 are obtained under a purely resistive variable load. Figure 7 (a) shown the output voltage of the battery in cyan, the buck dc-dc converter input current in pink, the load current in red and the control signal of the transistor Q1. The operation of the PEM fuel cell emulator under sudden variation of the load current is illustrated by Fig. 7 (b). This variation is typical and is in conformance with the PEM fuel cell model. The output voltage of the PEM fuel cell emulator is used to supply a boost dc-dc converter used to controller the power from PEM fuel cell emulator. The resulting voltage is used to power the battery rack directly.

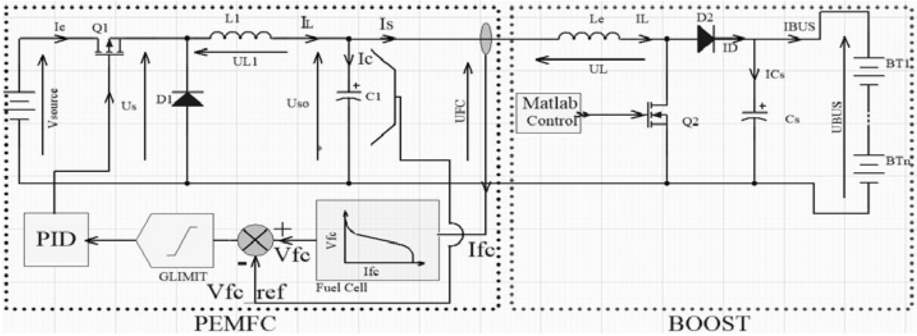



**Fig. 5.** Schematic diagram of the PEM fuel cell emulator

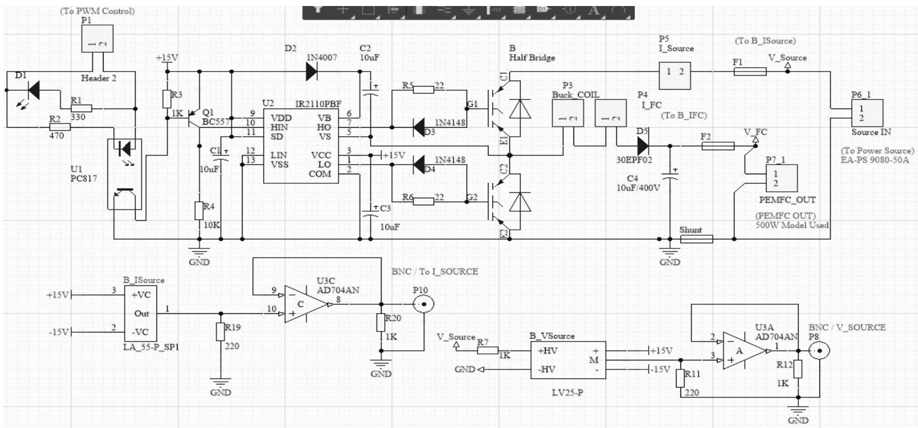
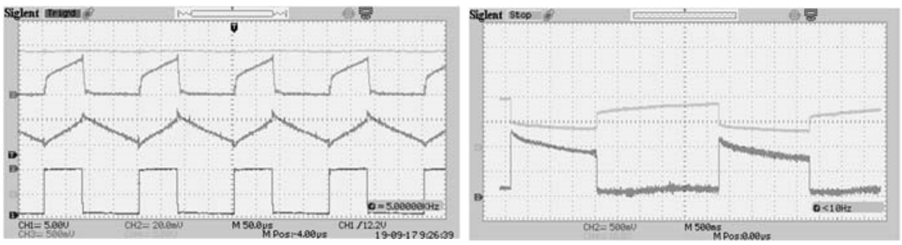



**Fig. 6.** Electronic Circuit of PEMFC Emulator




(a) (b)

**Fig. 7.** PEM fuel cell emulator results

The energy management algorithm fixes three phases of operations: When $V_{bus}$<84 V. The PEM fuel cell must supply the battery and the load power. When 84 <$V_{\text{bus}}$< 88 V, the batteries are kept in the slow charging mode and the PEM fuel cell must charge the battery and supply load. When $V_{\text{bus}}$> 88 V: The Fuel cell switches off and the batteries ensure the supply of the load alone. The developed real-time setup is illustrated in Fig. 8.

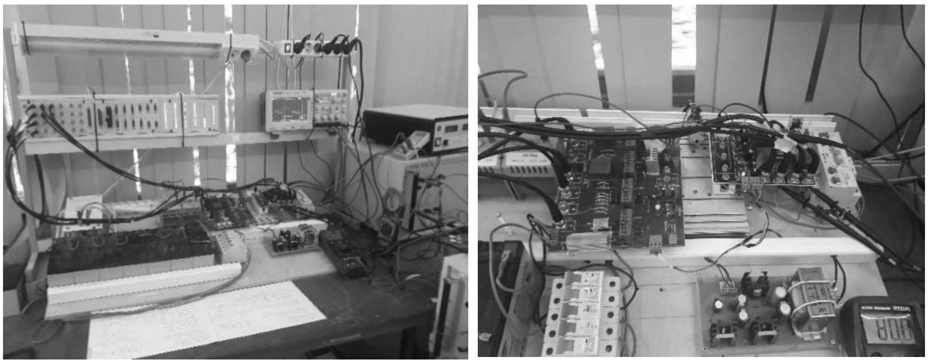


Fig. 8. Complete Operational system

## 6. Conclusion

The topology and the energy management proposed in this work can satisfy the power demand of the electric vehicle and ensure the respect of the constraints imposed on the energy sources (dynamics of the PEM fuel cell and provide or absorb the power peaks by the hybrid storage system). The simulation and experimental results show that this topology remains efficient, safe and simple although the presence of an additional converter. In addition, it offers good performance in terms of autonomy and power availability.

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