EXPERIMENTAL STUDY ON POWER CHARACTERISTIC CURVES OF A PORTABLE PEM FUEL CELL STACK IN THE SAME ENVIRONMENTAL CONDITIONS

CĂTĂRIG (RUS) T., RUS L.F.
Technical University of Cluj-Napoca, Faculty of Building Services,
21 December 1989 no.128-130, Cluj-Napoca, tania.catarig@insta.utcluj.ro

Abstract – Due to the depletion of fossil fuels and greenhouse gases, fuel cells have received, in the last years, a special attention beeing a viable alternative for electricity necesities, and thermic in some cases. Fuel cells are considered one of the most promising devices due to its cleanliness, modularity, silence and high potential capability. In this paper is presented the principle of operation of a portable proton exchange membrane fuel cell stack and the power variation curve in same environmental conditions.

Keywords: fuel cell stack, electrolyzer, storage canisters, USB data monitor.

1. INTRODUCTION

Fossil fuel reserves are finite and will be depleted in 50-100 years time. The continued use of fossil fuels generates greenhouse gases that are the cause of global warning and climate change [1].

The late of the 1990’s an international protocol, called Kyoto Protocol, aimed at fighting global warming. The goal of this protocol is to achieve the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate system [2]. Because of the Kyoto Protocol and the development in science, fuel cells technology received an increasing attention from researchers and producers as beeing one of the future technology.

Fuel cells represent a radically different approach to energy conversion, one that could replace conventional power generation technologies.

The principle of operation of a fuel cell is almost as battery’s principle, ie electrochemical conversion. Fuel cells differ from conventional batteries in that they consume the reactant, which must be replenished continuously in a closed system. Another difference is that the electrodes within a battery change and become depleted during the charging and discharging cycle, whereas fuel cell electrodes are catalytic and relatively stable. By construction, the fuel cell structure remains invariable in time, meaning that as long as fuel and oxidant are provided the fuel cell will produce electricity (in some conditions).

2. THE OPERATING PRINCIPLE OF A PROTON EXCHANGE MEMBRANE (PEM) FUEL CELL

There are several types of fuel cells, but all are based on the same operational principle, namely electrochemical conversion. This is the direct transformation of chemical energy stored in various active materials into electrical energy [3]. Conversion is called direct because between the initial and final energy form is not interposed any other intermediate form.

Indirect energy conversion systems have more processing stages between which is found necessarily in the form of heat or mechanical. Direct conversion of energy eliminates mechanical or thermical energy link, achieving higher performance, which not depends on the limited efficiency of thermal machines, ie not depends on Carnot limits. The idea to obtain power by converting chemical energy directly occurred when the question of performing a reverse phenomenon in the electrolysis of water was made, that is to get electricity from the reaction between hydrogen and oxygen [4,5]. In figure 1 is presented a comparation between energy conversion of fuel cells, batteries and heat engines.

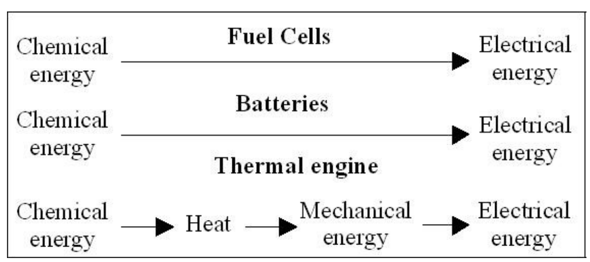

Fig. 1 - Schematic representation of energy conversion of fuel cells, batteries and heat engines

Basically, the energy released from oxidation of conventional fuels, generally used as heat can be converted directly into electricity with great efficiency. As in nearly all the oxidation reactions involved in electron transfer between fuel and oxidizer, it is obvious that the chemical energy of oxidation can be converted directly into electricity.

Achieving direct conversion of chemical energy into electrical energy can not run without an element that contains an anode, a cathode and an electrolyte that can be fed directly with fuel and air, as is shown in figure 2.

Fuel rich in hydrogen (or pure hydrogen) is introduced at the anode where a catalyst separates the electrons from protons. The protons (or positive ions) pass through the electrolyte (a proton exchange membrane) to the cathode where it combines with oxygen from air and forms water and heat, the only waste products.

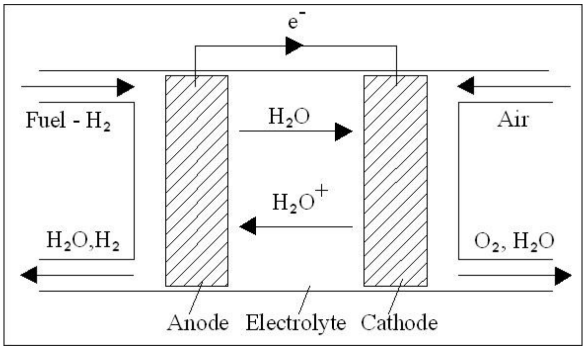

Fig. 2 - Schematic representation of operating principle of a proton exchange membrane fuel cell

Electrons formed at the fuel cell's anode can not pass directly through the electrolyte at the cathode side, because the membrane is electrically insulating, and are forced to travel in an external circuit. This movement of electrons causes electricity production [6].

3. FUEL CELL EFFICIENCY

The efficiency of a fuel cell depends on the amount of power drawn from it. With the increasingly power the higher current intensity gets, but also increases losses in the fuel cell. As a general rule, as long as the power drawn is higher the efficiency is lower. Most losses are manifested as a voltage drop in the cell, so that the efficiency of a cell is almost proportional to voltage. Most losses that occur in a fuel cell are due to electrochemical reaction kinetics, internal resistance, internal currents, mass and concentration losses [7,8]. A typical cell has an efficiency of about 50%, which means that 50% of the energy content in hydrogen is converted into electricity, and the remaining 50% can be converted into heat.

For presented case, a portable PEM fuel cell, must be taken into account the losses due air supply (the oxidant for the reaction is air at standard conditions, not pure oxygen). This reduce the efficiency significantly. In addition, fuel cell efficiency decreases with increasing load and with the constructive mode (as the fuel cell is smaller the efficiency will be lower).

4. PEM FUEL CELL APPLICATIONS

Due to their attractive properties, fuel cells have been developed and implemented in many applications. The main important categories of PEM fuel cells applications are devided into three broad areas:

- fuel cells for transport – provide either primary propulsion or extending capability for vehicles;
- fuel cells for stationary power – are units designed to provide power to a fixed location;
- portable fuel cells – those fuel cells designed to be moved.

In table 1 are presented some exemples of PEM fuel cells applications by the three broad areas.

Table 1. Exemples of PEM fuel cells applications

Transport applications sector	Stationary applications sector	Portable applications sector
Typical power range		
1 kW to 100 kW	0.5 kW to 400 kW	1 W to 20 kW
• Material handling vehicles; • Fuel cell electric vehicles; • Utiliary fuel cell vehicles; • Trucks; • Buses; • Trains; • Submarines; • Boats.	• Prime power source; • Large stationary combined heat and power – CHP; • Small stationary combined heat and power – micro-CHP; • Uninterruptible power supplies – UPS.	• Auxiliary power units – APU for campervans, boats and lighting; • Military applications; • Large and small personal electronics for mp3 players, cameras, laptops; • Toys; • Educational kits.

The global economic recession had negative effects for some fuel cells producers and caused them to go out of business. But for others, the last five years, were very succesfull as fuel cells became more populare for end users. That was seen in the growth of fuel cells shipments that rapidly accelerated. Portable fuel cells knew the most rapid rate of growth as fuel cells educational devices and auxiliary power units were sold to consumers.

In terms of delivered units, as it can be seen in figure 3, the portable sector is the largest, accounting almost 95% of total shipments in each year since 2009.

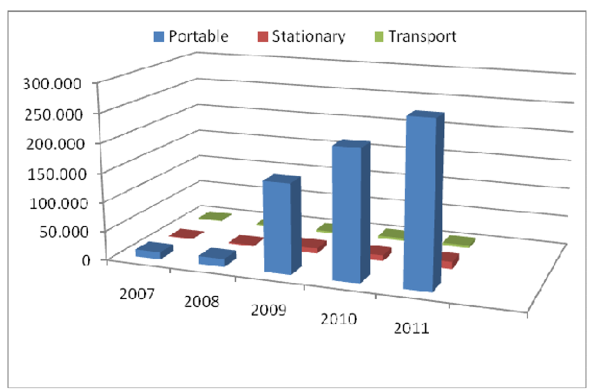

Fig. 3 - Fuel cell units delivered from 2007 to 2011

For all that, the portable sector represents only 2.6% of global megawatts installed because these units are smaller then 10 W [9]. This can be observed in figure 4.

These differences will continue because stationary and transport applications found their maturity and are included in large and prospective projects.

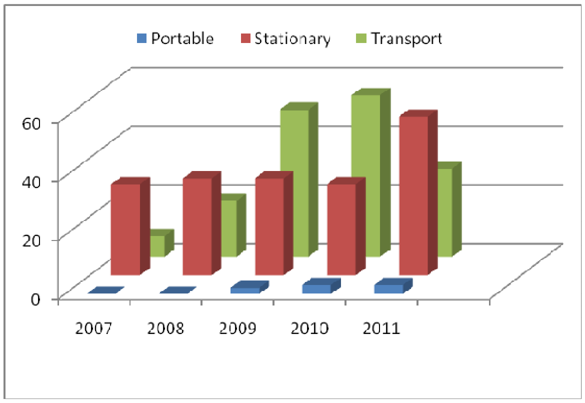

Fig. 4 - Megawatts installed from 2007 to 2011

5. EXPERIMENTAL SET-UP

The experimental study was held in the Research Laboratory of the Faculty of Building Services of the Technical University from Cluj-Napoca that has an educational kit called "Clean Energy Trainer". The goal of this educational kit is to familiarize the students with the interrelationship of renewable energy sources and hydrogen, but beyond this goal, the educational kit can be used in some experimental research studies. The educational kit has in his componence: two solar modules, a wind generator, two electrolyzers, four storage canisters, a fuel cell stack, a USB data monitor, a software, a consumer (a house with two lamps), an anemometer, a luxmeter, a fan, a lamp, bottle with distilled water, stop watch, hoses and cables. This components can be used in different ways, but for the experimental study were included only those that can be used with the fuel cell stack.

5.1. Electrolyzers and storage canisters

In order to be able to operate the fuel cell stack, hydrogen must be available. This can be produced with the electrolyzers (see fig. 5) by decomposing distilled water into hydrogen and oxygen. Distilled water is used to avoid poisoning the proton exchange membrane of the fuel cells with possible impurities.

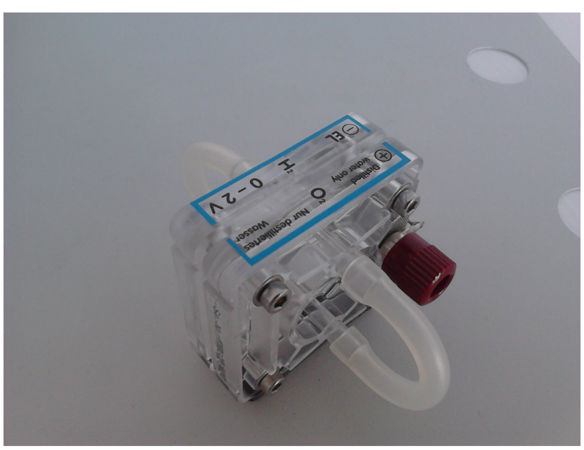

Fig. 5 - An electrolyzer used to produce hydrogen

The electrolyzers can be powered from the solar modules, or USB data monitor or the wind generator. For the presented case the USB data monitor was used.

The electrolyzers have each an hydrogen production of 5 cm^3/min and an oxygen production of 2.5 cm^3/min, ie two parts hydrogen and one part oxygen. The constructive dimensions of an electrolyzer are LxWxH (length, width, height) 57x40x50 mm and weights 54 g.

The hydrogen and oxygen produced by the electrolyzers are stored in storage canisters (see fig. 6).

Fig. 6 - Storage canisters for hydrogen and oxygen

The storage canisters have a capacity of 30 cm^3 and are provided with hoses that lead the fluids to the fuel cell stack. The hoses have clips that gives us the posibility to open or close the fluid circuit.

5.2. USB data monitor and Clean Energy Trainer software

The USB data monitor (see fig. 7) can be used as a DC voltage sources (as in the case of electrolyzers), as a source, as a measuring device and as a drain simulator. With this device and proper software investigations for analysing components and investigating systems can be made.

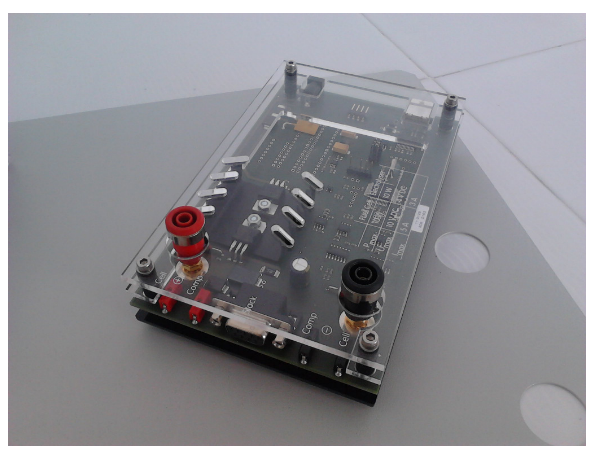

Fig. 7 - The USB data monitor

The USB data monitor has a maximum power of 10 W, the voltage for the eletrolysis mode is between 0÷4 V and for the fuel cell mode is between 0÷10 V. The current for the eletrolysis mode is between 0÷3 A and for the fuel cell mode is between 0÷4 A. The dimensions of the USB data monitor are 160x1000x40 mm and weights 1400 g.

With the Clean Energy Trainer software, that has an interface like in figure 8, various characteristic curves can be recorded. The software can operate in manual and in automatic mode.

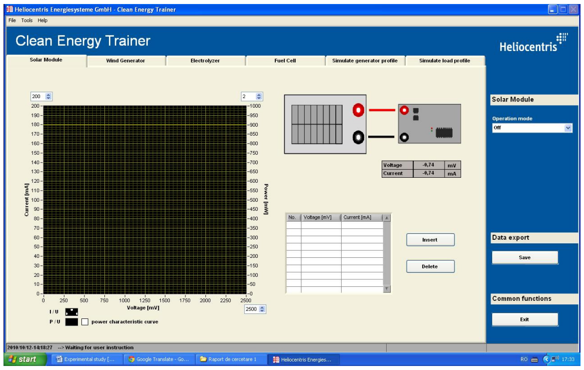

Fig. 8 - The software's interface

The software is divided into the respective thematic blocks through various tabs: solar module, wind generator, electrolyzer, fuel cell, simulate generator profile, simulate load profile.

5.3. Fuel cell stack

With the fuel cell stack, hydrogen is converted into electrical energy and can be used by a consumer. The fuel cell stack, presented in figure 9, of the Clean Energy Trainer educational kit is compound with five fuel cells that can be taken apart. In doing so, it is possible to represent different levels of output.

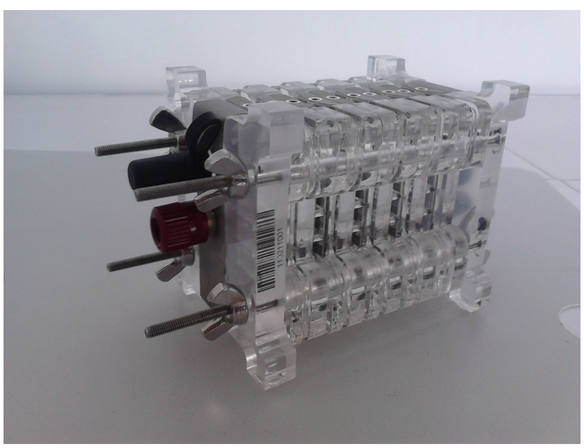

Fig. 9 - The fuel cell stack

The fuel cell stack has a maximum power of 1 W. The power of each fuel cell is 200 mW. The voltage generated by each cell can be between 0.4 and 0.96 V. The constructive dimensions of the fuel cell stack are LxWxH 175x70x60 mm and weights 430 g. In figure 10 are presented the five individual fuel cells.

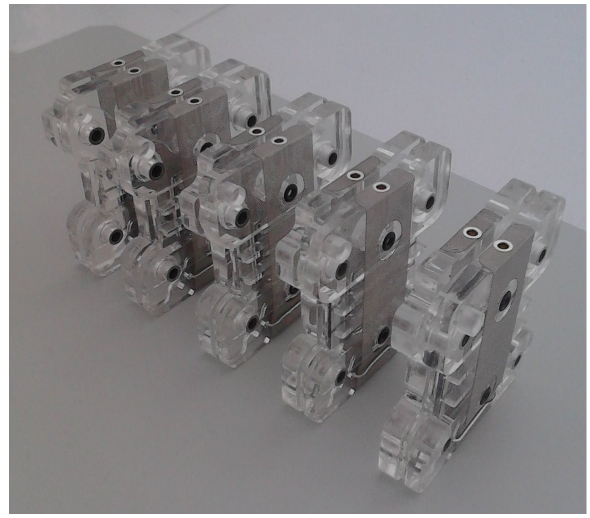

Fig. 10 - The five fuel cells that compound the stack

5.4. Achievement of the experimental installation

In order determine the characteristic curves of the fuel cell stack the experimental installation must be set-up. At first it is necessary to connect the electrolyzers to the storage canisters to the USB data monitor and to a PC in order to generate hydrogen. Here, the USB data monitor is used as a DC voltage source for the electrolyzers. After hydrogen is produced, the fuel cell stack is connected to the canisters were hydrogen was stored in. The hydrogen outlet of the fuel cell stack is opened for one second and then closed to flush the fuel cell stack. Since impurities can collect on the hydrogen side during the operation of the fuel cell stack, it must be flushed regularly in order to maintain a sufficiently high concentration of hydrogen in the fuel cell. After the fuel cell stack is flushed, hydrogen must be generated again to complete the storage canisters with the quantity of hydrogen used for flushing the stack. Then the USB data monitor is disconnected from the electrolyzers and connected to the fuel cell stack, as is shown in figure 11.

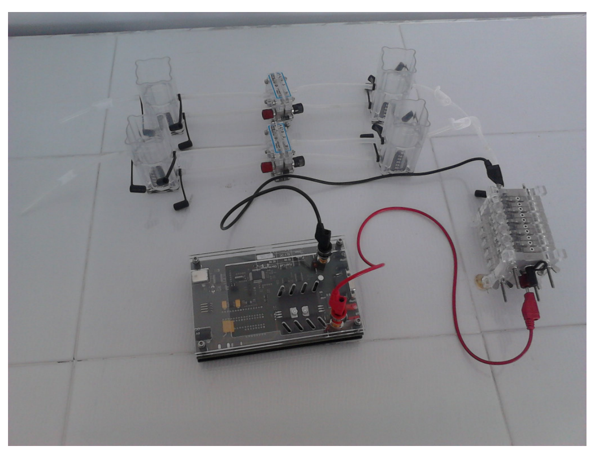

Fig. 11 - The experimental set-up

6. RESULTS AND DISCUSSION

Although a single storage canister has a capacity of 30 cm^3 of fluid, the measurements on voltage, current and power of the fuel cell stack were performed with 10 cm^3 respectively 15 cm^3 of fuel.

The measurements on the fuel cell stack, with different quantity of hydrogen, were performed in same conditions, ie automatic mode of the Clean Energy Trainer software, at atmospheric pressure and an ambiental temperature of 21.1°C.

The experimental plant was put into operation, the outlet of hydrogen and air of the fuel cell stack was opened until the imposed quantity of fuel was consumed. The results obtained were recorded and centralised by the software through graphs that are presented in figure 12 and 13.

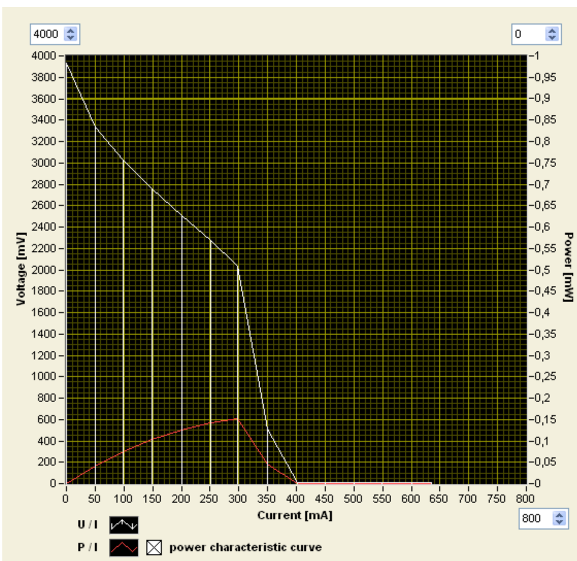

Fig. 12 - The current-voltage characteristic curve and the power characteristic curve obtained with 10 cm^3 of hydrogen

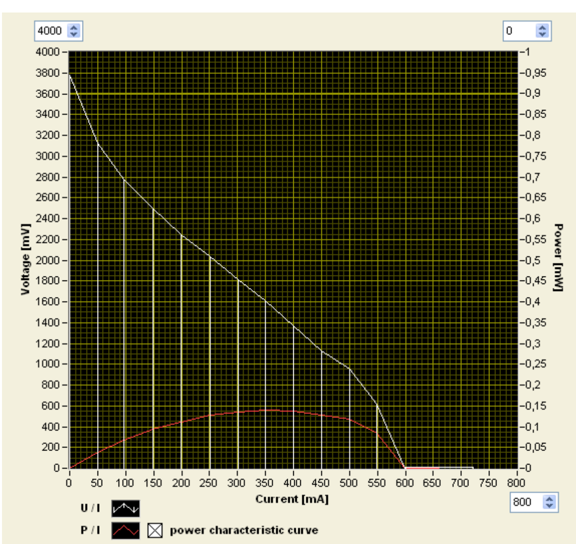

Fig. 13 - The current-voltage characteristic curve and the power characteristic curve obtained with 15 cm^3 of hydrogen

In the following will be presented voltage drops that occur in a fuel cell with the exemplification on the current-voltage characteristic curve of the first graph.

The theoretically possible voltage of a hydrogen fuel cell in standard conditions is 1.23V. In practice and in this case losses occur through kinetic inhibition of the reaction, internal resistance and insufficient diffusion. Therefore the delivered voltage of an individual cell, like it was presented earlier, is actually 0.4÷0.9 Volts.

The difference between the theoretical voltage and delivered voltage is called overvoltage and is caused by the speed of the conversion of hydrogen and oxygen. On graphs, the overvoltage occurs and can be observed between the values of 0÷100 mA of the current. Between the values 100 mA and 300 mA appears the internal resistance which is caused by the resistance against the current flow in the electrolyte. Here the voltage decreases linearly with the increase of the current.

In the first graph near the value of 300 mA and 2 V the maximum power is reached. After that, the diffusion overvoltage occurs due to the faster consumption of the gases by the electrochemical reaction at the catalyst. A typical sign for this diffusion overvoltage is a sudden downward bend of the current-voltage characteristic curve. In this graph, after the diffusion overvoltage occurs, it can be observed a straight horizontal line between the value of 400 mA and 650 mA. This line is explained by the fact that, even the 10 cm3 of hydrogen were consumed, an insignificant quantity of hydrogen, for the process, is still in the cells and the software is recording continuously dates, until the whole quantity of hydrogen will be used.

In the second graph the diffusion overvoltage can not be observed as well as in the first graph, but it occur. Because the amount of hydrogen in this case is higher, the diffusion overvoltage is more extended from the first graph. The straight horizontal line it can be seen as well as in the first case with the same explanations.

In the table 2 are presented the maximum and the average power obtained in each experimental study.

Table 2. The values extracted from the power characteristic curves of each study

	Study 1with 10 cm^3 of hydrogen	Study 2 with 15 cm^3 of hydrogen
P_{max}	0.6 W	0.56 W
$P_{average}$	0.23 W	0.32 W

From table 2 can be observed that maximum power in study 1 is higher than in study 2, but the average power is smaller than in the second case. Even if at first it was expected that the maximum power and the average power from the first study, the one performed with 10 cm^3 of hydrogen, to be smaller than in the second study, in reality the maximum power obtained in the first case is higher than the second one due to the slowly voltage decrease. This slightly decrease can be put into the account of internal losses that can vary greatly especialy at a small installation, like the one that measurements were made on. It is also possible that the incurred losses during the process of electricity production to be a result of small quantity of fuel used.

If the two study cases are compared and it goes from the fact that "as long as the power drawn is higher the efficiency is lower" it can be assumed that using a smaller amount of hydrogen for electricity production is more efficient than using a larger amount of hydrogen, and that is correct.

7. CONCLUSION

Considering that PEM fuel cell stack can have a maximum power of 1 W, one can appreciate that the values resulted from the experiment are relatively acceptable. The losses that occur in a portable PEM fuel cell stack are very important and can reduce significantly the efficiency of fuel cell stack.

Although measurements made in the Research Laboratory of the Faculty of Building Services on the educational kit, did not led to noticeable conclusions on the possible improvements that can be done for reducing voltage losses and increasing power extracted from the fuel cell stack, because the experimental stand has a small operating capacity, some conclusions were made:

- at a small amount of hydrogen the diffusion overvoltage is higher;
- at a larger quantity of hydrogen the voltage losses are lower;
- at a larger quantity of hydrogen the power characteristic curve does not present a downward bend, has a linear ascension/descension;
- by using a large amount of hydrogen the current and the voltage will be higher, and so the power characteristic curve will be improved;

To reach maximum power offered by educational kit, might try to modify ambient parameters, namely to rise the ambient temperature, and to be observe what influence has on the power. But this study will be the subject to a following experiment.

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