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# Experimental study of the static behaviour of the PEM fuel cell

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***Abstract*— This work proposes and justifies an easy electric model of a power generation system based on a PEM fuel cell, the H-Tec PEM Power Module of 1.2W. This model has been developed by means of experimental data obtained in our laboratory.**

***Keywords*— Fuel cell; PEMFC; Static; Modeling; Experimental.**

## I. INTRODUCTION

A fuel cell system is one of the environmentally friendly alternative power systems to conventional fossil power systems. PEM fuel cell is considered to be a promising power source, especially for transportation and stationary cogeneration applications due to its high efficiency, low-temperature operation, high power density, fast startup, and system robustness [1]. PEM fuel cells are suitable for portable, mobile and residential applications [2].

In this study; firstly, general information about the fuel cells basic operation is presented. Then the static mathematical models of the PEM fuel cell are investigated and presented. On the other hand, the characteristic of 1.2 W PEM fuel cell is obtained by experiments.

## II. FUEL CELL BASIC OPERATION

The fundamental structure of a PEMFC fuel cell can be described as two electrodes (anode and cathode) separated by a solid membrane acting as an electrolyte (Fig 1). Hydrogen fuel flows through a network of channels to the anode, where it dissociates into protons that, in turn, flow through the membrane to the cathode and electrons that are collected as electrical current by an external circuit linking the 2 electrodes. The oxidant (air in this study) flows through a similar network of channels to the cathode where oxygen combines with the electrons in the external circuit and the protons flowing through the membrane, thus producing water.

A typical type of fuel cell is the PEMFC. The electro-chemical reactions at the anode and cathode in a PEMFC are shown below:

Anode reaction: $H_2 \leftrightarrow 2H^+ + 2e^-$ (1)

Cathode reaction: $O_2 + 2H^+ + 2e^- \leftrightarrow H_2O$ (2)

Total cell reaction: $H_2 + \frac{1}{2}O_2 \leftrightarrow H_2O$ (3)

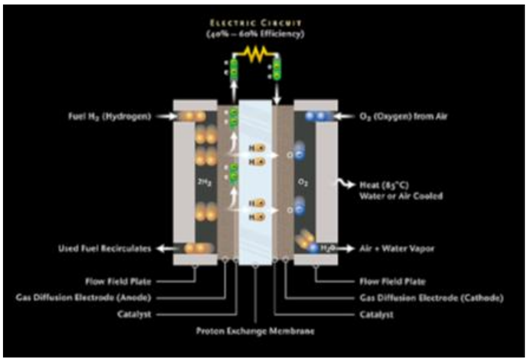

Fig.1 The operating principle of PEMFC.

## III. PEMFC STATIC BEHAVIOR MODEL

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This section presents an electrochemical model, which can be used to the static behavior of PEMFC stack .This mathematical model uses a group of parameters, whose definition is essential for the best simulation results. It is wise at this point to define the output voltage of a single cell, which can be defined as follow [3]:

$$V_{cell} = E - \eta_{act} - \eta_{ohm} - \eta_{dif} \tag{4}$$

And, for N cells connected in series, forming a stack, the voltage, Vstack, can be calculated by:

$$V_{stack} = N_{cell}.V_{cell} \tag{5}$$

Where E is the average thermodynamic potential of each unit cell and it represents its reversible voltage; $\eta_{act}$ is the voltage drop associated with the activation of the anode and of the cathode; $\eta_{ohm}$ is the ohmic voltage drop associated with the conduction of protons and electrons; and $\eta_{con}$ represents the voltage drop resulting from the decrease in the concentration of oxygen and hydrogen.

The individual terms in (4) are defined by [3,7,8]:

$$E_{cell} = 1,229 - 0,85.10^{-3}\left(T - 298,15\right) + 4,3085.10^{-5} T \left[\ln PH_2 + 0,5 \ln PO_2\right] \tag{6}$$

$$\eta_{act} = \xi_1 + \xi_2 T + \xi_{3.} T \ln(CO_2) + \xi_4 . T \ln(I) \tag{7}$$

$$\eta_{ohm} = I(R_m + R_c) \tag{8}$$

$$\eta_{con} = -B \ln(1 - \frac{J}{J_{\lim}}) \tag{9}$$

Where:

- $P_{H2}$ and $P_{O2}$ :are the partial pressures (atm) of hydrogen and oxygen, respectively;
- T: is the cell temperature (K);
- $i_{FC}$: is the cell operating current (A);
- CO2: is the concentration of oxygen in the catalytic interface of the cathode ($mol/cm^3$);
- ξi (i =1..4): represent parametric coefficients;
- $R_m$: is the equivalent membrane resistance to proton conduction (Ω);
- $R_C$: is the equivalent contact resistance to electron conduction (Ω);
- $J_{lim}$: is the maximum current density ($A/cm^2$);
- B: is a parameter dependent on the cell type and its operation state (V); and
- J: is the actual cell current density ($A/cm^2$), including the permanent current density Jn.

$CO_2$ is the concentration of oxygen dissolved in a water film interface in the catalytic surface of the cathode in (mol/cm3), estimated on the basis of the oxygen partial pressure and cell temperature by the law of Henry [4] :

$$CO_2 = \frac{PO_2}{5.08 * 10^6 \exp^{(\frac{-498}{T})}} \tag{10}$$

The equivalent resistance $R_m$ of the electron flow and $R_C$ is the proton resistance considered as constant [3], [5]:

$$Rm = \frac{\rho_M . l}{A} \tag{11}$$

In which $\rho_M$ is the specific resistance of the membrane (Ω.cm). A is the membrane active area ($cm^2$), and l is the thickness of the membrane (cm). We can assume the membrane thickness to be $178 \times 10^{-4}$cm, which pattern is Nafion117:7 mil.

The Following expression for the specific resistance is used [3,5]:

$$\rho_M = \frac{181.6\left[1+0.03\left(\frac{T}{A}\right)+0.062\left(\frac{T}{303}\right)^2\left(\frac{I}{A}\right)^{2.5}\right]}{\left[\psi-0.634-3\left(\frac{I}{A}\right)\right]\exp\left[4.18\left(\frac{T-303}{T}\right)\right]}$$

(12)

Where the term is the specific resistance (Ω.cm) at no current and at 30$^{o}$C; the exponential term in the denominator is the temperature factor correction if the cell is not at 30$^{o}$C.The parameter Ψ is an adjustable parameter with a possible maximum value of 23.

## IV. EXPERIMENTAL TEST AND RESULTS

### A. *Experimentation Description*

The PEMFC model [H-TEC PEMPower1 FuelCell] (Fig.1) used for the tests is a 1.2 W. With an active cell area of about 16 cm²,with a membrane model Nafion 117, fed by pure gases $O_2$ and $H_2$ and stacks of (04) cells. The fuel cell can operate from atmospheric pressure to about 0.01bars for $H_2$ and 0.02 for $O_2$.

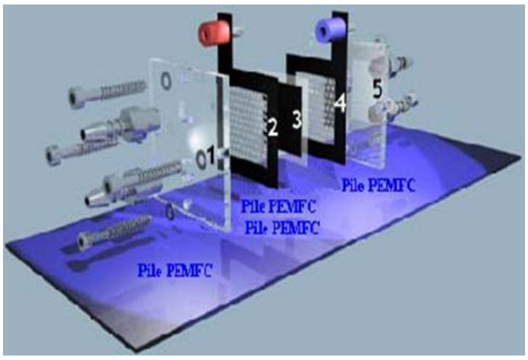

Fig.2 Single cell of H-Tec pemfc Cder.

The measurements were made by:

- ✓ Pressure regulator, [$pH_2$,$pO_2$]: There has manodétenteurs two located at the exit bottles of reactive gases and two pressure control valves located at the entrance of the cell, the characteristics of which have been mentioned above.
- ✓ Thermocouple, [T]: There has four thermocouples type K -10° C …..+100°C.
- ✓ Humidifier [0 ≤ Ψ≤ 22] Knowing the boundary conditions humidification of the membrane, we can know its coefficient.

The method used for humidification of the membrane is that of the injection of water droplets in the gas stream directly by injecting a larger amount for hydrogen than for oxygen.

- ✓ Acquisition Card [OMEGA OM-3000].
- ✓ Precision Multimeter: the PM2525.
- ✓ Rheostat.
- ✓ Digital voltmeter.
- ✓

Fig. 3 shows the laboratory test bench, the fuel cell and the measurement units.

Fig. 3 H-Tec pemfc power module in Cder laboratory.

A detailed description of a similar fuel cell test bench can be found in references [6].

### B. *Experiments Results*

To obtain the equivalent electrical model of power module, we have carried out experimental studies in our laboratory Cder Alger's (Fig. 3) with the H-Tec power system.

Some measurements have been acquired in order to adjust the stationary behaviour of the stack to its characteristic curve.

Fig.4 shows the measured V-I characteristic of the fuel cell at 25°C. The same voltage is inversely proportional to the current density to a minimum value which is negligible considered equal to 0.00 mA/cm$^2$, we obtain a maximum value of the open circuit voltage of 4.12 V. Whereas a maximum current density of 35.46875 mA/cm$^2$, we obtain a minimum value of potential1.55 V.

We note as well as high current densities the performance of each battery assembly decreases compared to a unit cell is due to the increase in losses, mainly resistive which increase (greater surface area). This is why we distinguish two sections in our curve, representing respectively the activation and ohmic polarizations while the concentration polarization does not appear.

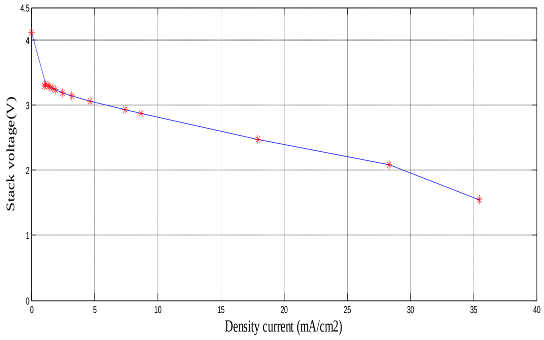

Fig. 4 Shows the measured V-I characteristic of the fuel cell at 25°C.

Fig. 5 shows the power of the stack, Points work best for this blend of four cell in series and using the optimization of maximum available power of the stack (called modern) for obtaining a powerful Maximum density P = 59.0032 mW/cm$^2$ are: Current density i = 28.3125 mA/cm$^2$ and voltage V = 2.084 V, obtained by R = 1 Ω.

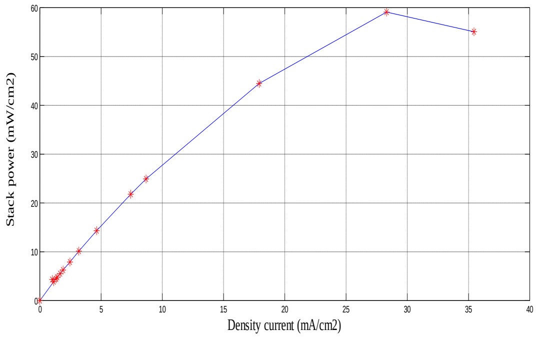

Fig.5 power of the stack vs density current

Fig. 6 shows the effiency of the stack .We note that the open circuit output which corresponds to R = ∞ is equal to 0.838 is greater than that of a unit cell and a blend of two fuel cell in series, but for other values, performance varies from 0.675 to 0.315 proportion to the load which varies from 45 to 0 Ω. For an assembly of four fuel cell in series, the ohmic polarization are much more important especially at high current densities, which is why the performance of high current density is relatively low. At low current densities we also observe a relative decrease in performance compared to the other two cases, this is caused by the decrease in ambient temperature (Tamb Case of a fuel cell = 24.40°C. Where two pemfc series $T_{amb}$ = 25.95° C).

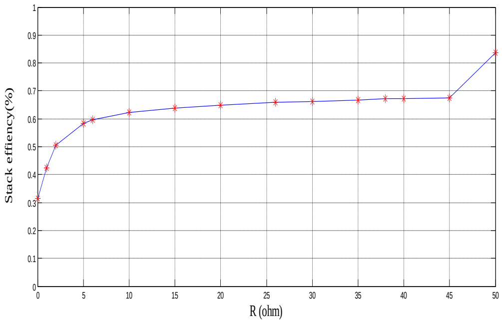

Fig.6 The effiency of the stack vs resistor (R)

Fig. 7 shows the effect of the load for this stack. The minimum voltage 1.55 V corresponding to a zero(0) charge and the voltage increases to a maximum value 4.12 V open circuit corresponding to R = ∞. Unlike the current intensity which is considered to be zero for a zero load. Same remark as to the proportionality of the load with respect to the voltage and current.

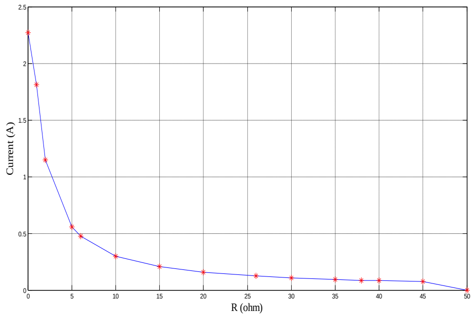

Fig.7 the current of the stack vs resistor (R)

TABLE 1: PARAMETER SET OF A 1.2W CDER STACK

| **Parameter** | **Value** | **Unit** |
|---|---|---|
| *T* | 298,15 | K |
| *R* | 8,314 | J/(kmol K) |
| *A* | 16 | $cm^2$ |
| *N* | 4 | / |
| $pH_2$ | 0,01 | bar |
| $pO_2$ | 0,02 | bar |
| $R_m$ | 0,126 | S |
| *Rc* | 0,0003 | Ω |
| *B* | 0,016 | V |
| *Ψ* | 14 | / |
| *L* | 230 | μm |
| $\xi 1_{théorique}$ | - 0,949 | |
| $\xi 1_{experimental}$ | - 1,053 | |
| $\xi_2$ | $0{,}02866\ln(A) + 4{,}3.10^{-5}\ln(C_{H_2})$ | |
| $\xi_3$ | $7{,}6x10^{-5}$ | |
| $\xi_4$ | $1{,}93x10^{-4}$ | |
| $J_{lim}$ | 0,0496 | $A/cm^2$ |

## V. CONCLUSIONS

The methods presented in this paper contribute on a very efficient way to the analysis and modelling of experimental data of a PEMFC. They are therefore very well adapted for fuel cell experimenters and designers.

The study of the steady-state response of the PEM fuel cell reveals that a good approximation has been performed because of the good agreement of the experimental and theoretical values.

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TABLE 2: EXPERIMENTS RESULTS OF A 1.2W CDER STACK

| **R(Ω)** | **U(V)** | **I(A)** | **i($mA/cm^2$)** | **P($W/cm^2$) $10^3$** | $\eta_{elec}$ |
|---|---|---|---|---|---|
| ∞ | 4,12 | 0,000000 | 0,000000 | 0,00000 | 0,83807973 |
| 45 | 3,32 | 0,0734 | 1,146875 | 3,807625 | 0,67534581 |
| 40 | 3,3 | 0,0820 | 1,03125 | 4,228125 | 0,67127746 |
| 38 | 3,3 | 0,0857 | 1,3390625 | 4,41890625 | 0,67127746 |
| 35 | 3,28 | 0,0928 | 1,45 | 4,756 | 0,66720911 |
| 30 | 3,26 | 0,1074 | 1,678125 | 5,4706875 | 0,66314076 |
| 26 | 3,24 | 0,1228 | 1,91875 | 6,21675 | 0,65907242 |
| 20 | 3,19 | 0,1576 | 2,4625 | 7,855375 | 0,64890155 |
| 15 | 3,14 | 0,2054 | 3,209375 | 10,0774375 | 0,63873068 |
| 10 | 3,06 | 0,2972 | 4,64375 | 14,209875 | 0,62245728 |
| 6 | 2,932 | 0,4750 | 7,421875 | 21,7609375 | 0,59641985 |
| 5 | 2,871 | 0,5552 | 8,675 | 24,905925 | 0,58401139 |
| 2 | 2,478 | 1,146 | 17,90625 | 44,3716875 | 0,50406835 |
| 1 | 2,084 | 1,812 | 28,3125 | 59,00325 | 0,42392189 |
| 0 | 1.55 | 2.27 | 35,46875 | 54,9765625 | 0,31504065 |