FUEL CELL STACK DESIGN AND CONSTRUCTION IMPLEMENTING A DC/DC CONVERTOR

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ABSTRACT

Fuel cells represent a great alternative for energy generation. There are many education institutes and research centers designing and developing new materials for fuel cells manufacturing; obtaining efficient topologies for control systems and power, and developing prototypes for stationary and mobile applications.

In this paper we report on the design and manufacture of an experimental fuel cell stack and the development of a conditioning power system (DC/DC converter) to supply a constant voltage output to low power systems.

The project was realized in two phases:

1) Design and manufacture of two fuel cell stacks; each stack using four Membrane-Electrode Assemblies (MEA). Bipolar plates with serpentine flow fields and end plates were made with a numerical control machine. The end plates were made out of aluminum; and contain the inlet and outlet of reactant gases. The current collectors were manufactured from brass. Thin silicon gaskets were designed and manufactured. MEA's were prepared using Nafion 115 and electrodes with carbon cloth as substrate for the Pt/C catalyst layer, and hot pressed.

2) A DC-to-DC boost type converter was designed, simulated and built to increase the stacks' output voltage.

Key words: fuel cell stack, converter DC-to-DC.

1. INTRODUCTION

Polymer Electrolyte Membrane Fuel Cells (PEMFC) are an attractive source for electric power generation. One of the challenges that PEMFC's are facing nowadays is how to lessen their components' costs. Besides, there is a necessity to develop systems of conditioning, where the power electronics has a great importance. For those purposes, many research and educational centers around the world are carrying out researches regarding this technology.

The main goal of this work is the design and manufacture of two low-power experimental PEM fuel cell stacks and the development of a conditioning system capable to keep a constant voltage output to feed a system of low power.

2.1 DESIGN AND MANUFACTURE OF TWO FUEL CELL STACKS

The activities were divided in three phases to accomplish the objective:

a) Manufacturing the stacks' components (end plates, bipolar plates, gaskets, etc.).
b) Manufacturing and electrochemical characterization of the MEA's.
c) Characterization of stacks' performance.

2.1.1 Final and bipolar plates

The final and bipolar plates were machined using a numerical control machine (CNC)from commercial graphite (FU 4369). The flow channels are serpentine [2] with a 30 x 29 mm active area. The inlet and outlet of reactant gases were made with 3.17mm (1/8") drills. The plates size is 45 x 45 x 5 mm as illustrated in figure 1.

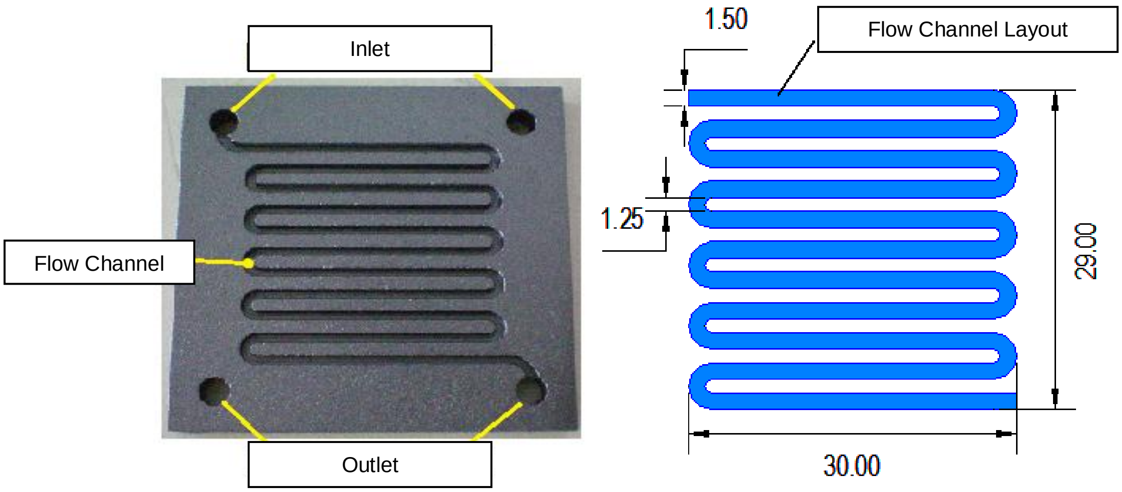


Figure 1. Bipolar plate serpentine flow channel layout

2.1.2 Supporting plates

The stack's supporting plates were made out of aluminum. They have different size perforations for each purpose 6.35 mm (¼") diameter perforations are to lock the cell together; and 8.71 mm (11/32") diameter perforations are for the inlet and outlet of reactant gases. See figure 2.

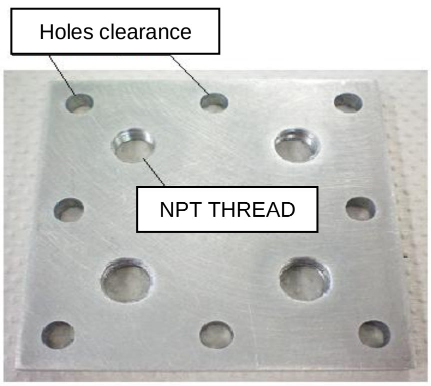


Figure 2. Stack's aluminum end plate

Figure 3. Acrylic mold to make gaskets

2.1.3 Gasket

Gaskets were made out of silicone rubber (Polisil P-85); with a thickness of 0.30mm. It was necessary to design and build an acrylic mold for gaskets manufacturing to allow better thickness control for the gaskets. See figure 3.

2.1.4 Current Collector

Brass plates were used as current collectors. Since reactant gases have to pass through them, 4 perforations had to be made on them. The perforations were concentric to those perforations on bipolar plates and have a diameter of 3.175 mm. A current collector is shown in Figure 4.

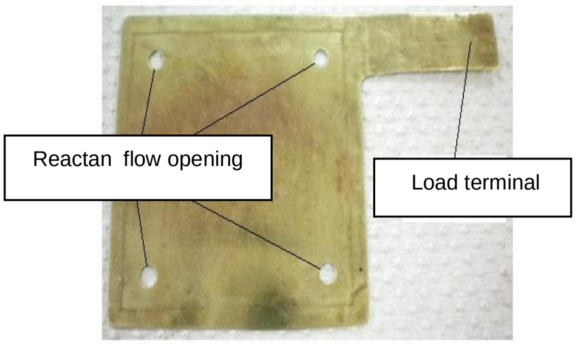


Figure 4. PEM Stack brass current collector

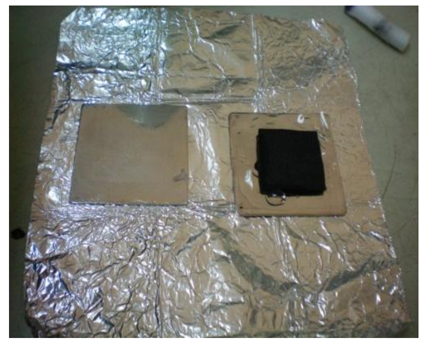


Figure 5. MEA with Nafion 115 and 0.5 mg Pt/cm^2.

2.1.5 Membrane Electrode Assembly (MEA)

The catalyst layers were fabricated from a catalytic ink by the screen printing and by the dripping method onto the gas diffusion layers. However, for areas over 4 cm^2 the dripping method was found to result in less catalytic waste.

The MEAs, see figure 5, were manufactured with Nafion® 115 as an electrolyte. The electrodes have an area of 7.78 cm^2 each, with a platinum content of 0.5 mg/cm^2. They were hot pressed at 120°C and 7800 lb for 3 minutes [1].

2.1.6 Stack Assembly

The stack was assembled connecting several cells in series using the bipolar plates, as illustrated in figure 6 in order to increase the output voltage and power, at constant current . The cell was pressed together untill a 20in-lbs torque was reached.

Figure 6. PEM fuel cell assembly and Stack

3.1 DESIGN AND MANUFACTURE OF A DC-DC BOOST TYPE CONVERTER

Although the voltage is increased when connecting the cells in series; it is not high enough for a practical application. Therefore a DC-DC boost converter is necessary to increase and regulate the voltage and the current [3].

For the DC-DC booster design, the values shown in figure 7 were used. The input and output values are the voltage and current that could be taken from the stack, and the voltage and current needed for a practical application, respectively.

Figure 7. Input and output voltage and current in converter

The convertor was developed in two phases:

1) Analysis and selection of the appropriate DC-DC converter.
2) Converter design and construction.

3.1.1 Analysis and selection

Some of the DC-DC converter types for fuel cells that can be found in literature [4] are listed in table 1.

Converter DC-DC	Input Power (Watts)
Full bridge DC-to-DC converters	500 to 1500
Push-pull DC-DC converter.	100 to 1000
Boost DC-DC converter	0 to 150

Table 1 Converters DC-DC for fuel Cell

The power that should be supplied for both the Full bridge and Push Pull converters range is higher than the output voltage of the stack made. Therefore the Boost type converter was chosen. The Boost converter electric circuit is shown in figure 8.

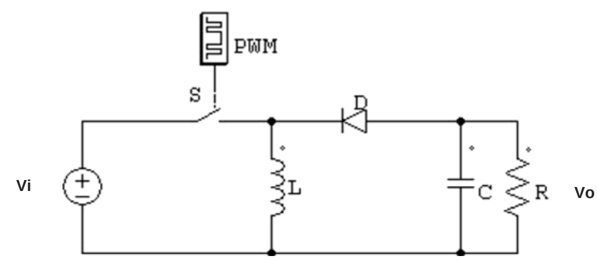


Figure 8. Electrical circuit of boost converter

3.1.1.1 Converter operation

In a DC-DC converter (see figure 8), the output voltage (V_o) is higher than the input voltage (V_i). The Boost converter uses an electronic switch (S) as commutation device. To activate or deactivate the switch a sign Pulse-width modulation (PWM) is necessary [3].

When the switch is “on”, the diode is inversely polarized so a closed loop is formed by the source and the inductor. The resulting current variation is a lineal constant increase.

When the switch is “off”, the diode is directly polarized (since the current in the inductor cannot vary instantly) and provides a path for the inductor current.

The converter output voltage (V_o) can be determined, by the equation 1.1. [5].

$$V_o = \frac{V_i}{1-\alpha} \quad (1.1)$$

where α represents the duty cycle that is defined as the time lag that the switch spends "on" [5].

3.2 Calculations

3.2.1. Selection of the duty cycle

Using the equation (1.1), the converter duty cycle was calculated as follows:

$$V_{\mathrm{o}} = \frac{V_{\mathrm{i}}}{1-\alpha} \qquad \alpha = 1 - \frac{V_{\mathrm{i}}}{V_{\mathrm{o}}} \rightarrow$$

Hence the duty cycle is 41.6%

3.2.2. Calculation for the value of the inductor

The equation (1.2) is applicable to calculate the minimal inductance of the permanent current [14].

$$L_{\mathrm{min}} = \frac{\alpha(1-\alpha)^2 R}{2f} \tag{1.2}$$

where R is the ohmic resistance under the converter output conditions and f is the commutation frequency. A value of 100 kHz was considered since the frequency rank for DC-DC boot type converters is between 300 kHz – 10MHz. The value of the inductor is 1.7µH.

3.2.3 Curl selection for the output voltage

The desired curl for the output voltage must be chosen to get the correct capacitor value. For this project and according to the equation 1.3 the curl is 0.8%.

$$\frac{\Delta V_o}{V_o} = \frac{\alpha}{RfC} < 0.8\% \tag{1.3}$$

3.2.4 Calculation of the capacitor

The capacitor value [5] is 216 µF and it was found with the equation (1.4)

$$C > \frac{\alpha}{Rf(\Delta V_o/V_o)} \quad (1.4)$$

Where α is the duty cycle, R the ohmic resistance of the load, f the commutation frequency, and $\Delta V_o/V_o$ is the output voltage curl.

3.3 Control by feedback

In order to get the output voltage and the current proposed, it's necessary design and build a closed loop control system [5]. It will allow examining and correcting the deviation between the out-parameters and the reference supplied by the control circuits.The scheme is shown in figure 9.

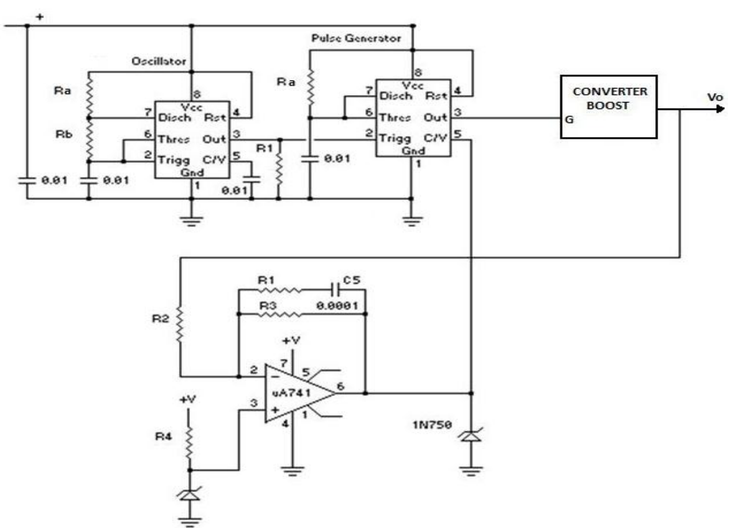


Figure 9. Connection between the control system and the converter.

3.3.1 Operation

The output voltage is measured and compared with a reference voltage. The error is used to control the duty cycle [6].

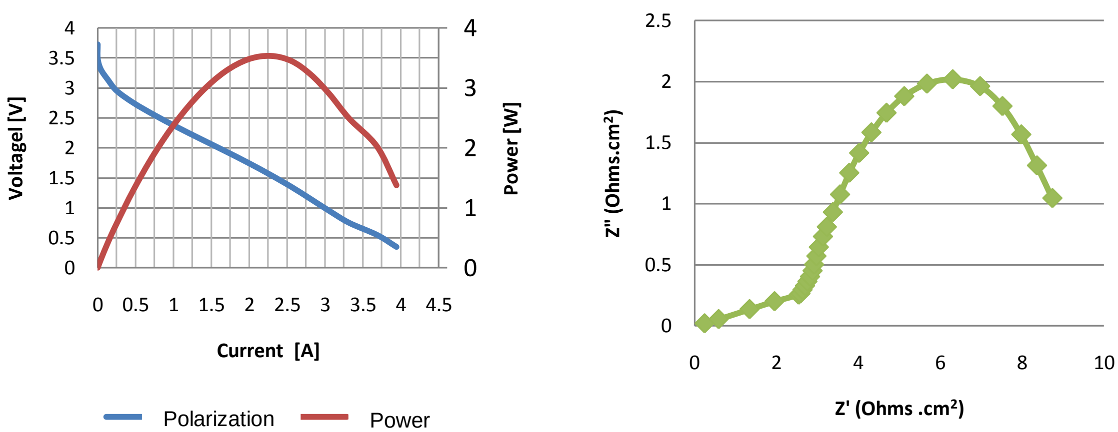
The amplifier (A741) compares the converter output voltage with a reference voltage. The compared voltage is delivered to a Zener diode (1N750) to produce an error signal. The error amplifier output voltage is compared with a squared-form wave, generated by the NE555 in a stable operation (oscillator). The PWM circuit output voltage is delivered in a unique pulse by the NE555 in a mono-stable operation (impulses generator), for the control of the MOSFET gate.

4.0 RESULTS AND CONCLUSIONS

Eight MEA's were manufactured, assembled and individually tested. These tests were made under a fuel cell operation temperature of 25°C, a gas flow of 0.20 $Lmin^{-1}$ and a relative humidity of 100%. Results of these tests are showed in table 2. After these tests were carried out, the MEA's were connected together into two stacks (four MEA's for each stack). Polarization curves, power density and impedance of the stacks are shown in figures 10 and 11.

No. MEA	Current densityat 0 V. [mA*cm^{-2}]	System ohmic Resistance [ohm*cm^2]	Max Power Density [mW*cm^{-2}]	Voltage (Max Power) [mV]	Current Density (Max Power) [mA*cm^{-2}]
1	501.28	1.84	113.84	400.00	284.61
2	451.93	1.34	84.06	402.83	208.69
3	479.47	1.40	103.05	349.47	294.90
4	393.04	1.49	101.98	429.62	237.38
5	392.46	1.43	93.03	369.66	251.67
6	512.78	1.37	151.36	390.11	388.00
7	278.69	1.51	84.95	349.69	193.22
8	385.46	1.38	104.64	389.97	268.35

Table 2 Individual cell characterization



a) b)

Figure 10. Performance results for stack number 1: a) Polarization curve (blue color) and power (red color) and b) measured impedance.

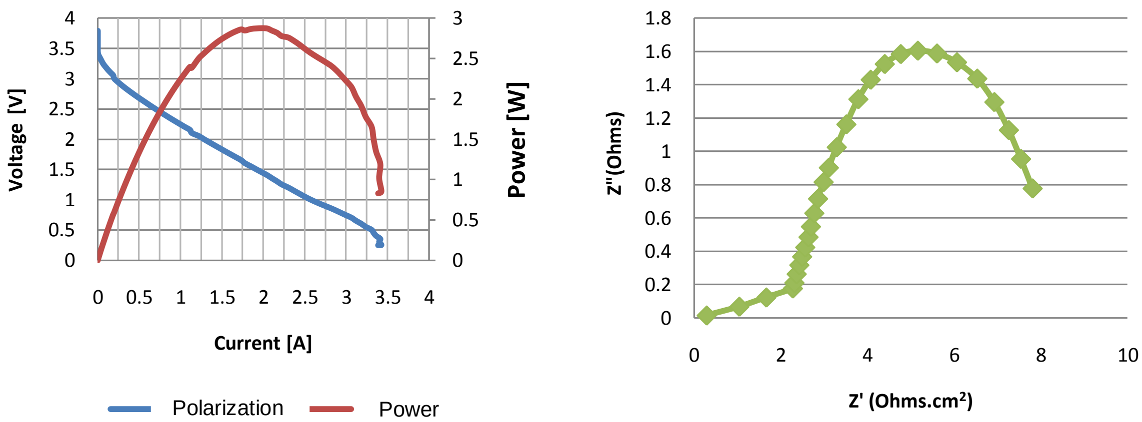


Figure 11. Performance of stack number 2: a) polarization curve (blue color) and power (red color), b) measured impedance.

As illustrated in figure 10 and 11, the stack No.1 has a peak power of 3.53 W at 2.28 A and 1.55 V with a resistance of 0.25 Ohms/cm^2. Stack No. 2 has a peak power of 2.88 W at 2.00 A and 1.50 V with a resistance of 0.29 Ohms/cm^2.

4.1 Simulation of DC/DC Converter

The values given in section 2.0 were evaluated by the PSIM software (for power electronic simulations).

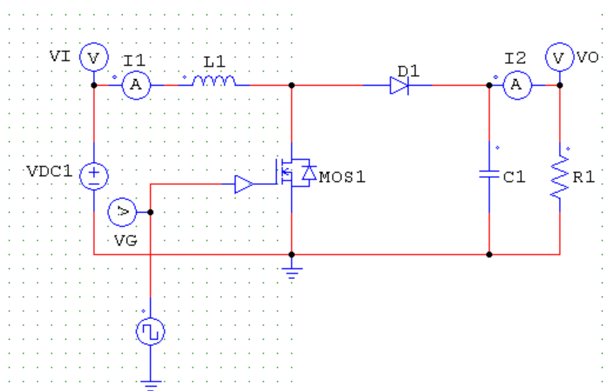


Figure 1. Simulated circuit in PSIM

The simulation results are illustrated in figure 12. If, for example, the input current I_1 has a value between 8 and 9 A (waveform of red color) then the output current I_2 (blue color) is constant with a value of 5A... If the input voltage V_I (pink color) is 7 V, then the output voltage V_O (yellow color) has a constant value of 12 V_{cd}.

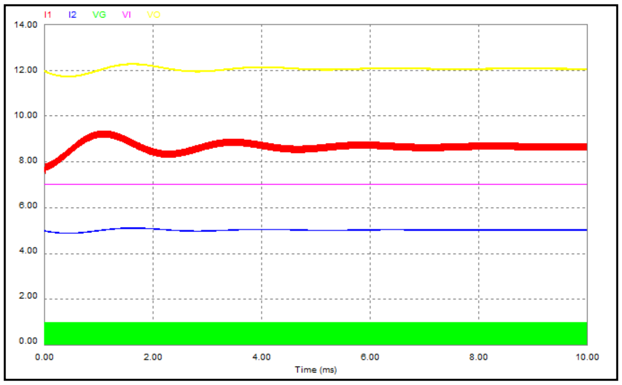


Figure 12. Waveform simulation

4.2 Converter and stack connected

Finally, the converter was connected to the stack and then a load (fan) of 12V_{DC} and 1 A. was plugged to the system as shown in figure 13. Since the converter increased the power from the stack from 3.53 W to 7 W, which allowed the fan to operate properly.

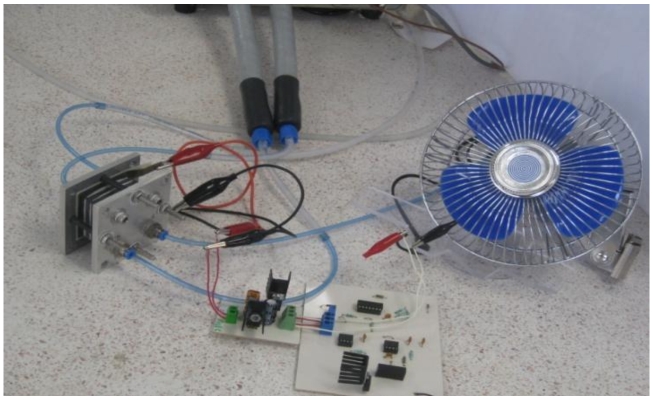


Figure 13. Connection convert, stack and load (fan)

4.3 Conclusion

In this project 2 low-power, fuel cell stacks were developed and integrated with a Boost DC-DC type converter. The results show that:

- Membrane-electrode assemble preparation needs to be further optimized in order to increase the power density of the stacks.
- It's necessary to propose a control circuit that enables work on highs frequencies to reduce the size of the topology of the circuit, without neglecting the converter efficiency.

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