Available online at www.sciencedirect.com
ScienceDirect
Journal of Power Sources 169 (2007) 334–337
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Short communication

Polymer electrolyte fuel cell mini power unit for portable application

F. Urbani [a,*], G. Squadrito [a], O. Barbera [a], G. Giacoppo [a], E. Passalacqua [a], O. Zerbinati [b]

[a] CNR-ITAE, via Salita S. Lucia sopra Contesse n. 5, 98126 S. Lucia, Messina, Italy
[b] Università del Piemonte Orientale, Dip. di Scienze dell'Ambiente e della Vita, via Bellini 25/g, 15100 Alessandria, Italy

Received 8 March 2007; received in revised form 16 March 2007; accepted 16 March 2007
Available online 30 March 2007

Abstract

This paper describes the design, realisation and test of a power unit based on a polymer electrolyte fuel cell, operating at room temperature, for portable application. The device is composed of an home made air breathing fuel cell stack, a metal hydride tank for H_2 supply, a dc–dc converter for power output control and a fan for stack cooling. The stack is composed by 10 cells with an active surface of 25 cm^2 and produces a rated power of 15 W at 6 V and 2 A. The stack successfully runs with end-off fed hydrogen without appreciable performance degradation during the time. The final assembled system is able to generate 12 W at 9.5 V, and power a portable DVD player for 3 h in continuous. The power unit has collected about 100 h of operation without maintenance.

Keywords: Fuel cell; Gas diffusion electrodes; Portable device; Stack; Air-breathing; Flow-field

1. Introduction

The interest on Polymer Electrolyte Fuel Cells (PEFC) technology as energy source for portable application has increased due to the characteristics of high energy density, high efficiency and no pollution of these devices [1–3]. "Air-breathing" stack is an emerging class of fuel cells for all those low power devices actually served by conventional batteries, because it does not require sub-systems for air supply and humidification. In any case, to replace batteries pack not only the stack has to be miniaturised but also the PEFC power system must be designed to be light and small in mass and volume. For these reasons the stack needs a special attention to the flow field design, diffusion layer realisation, membrane and electrodes configuration moreover the integrated system needs an efficient hydrogen storage device and miniaturised connections. Recently, some papers on the whole fuel cell system have been published [4–6] showing that their application is gradually gaining ground. Looking at the open questions, our activity was devoted to the acquisition of the know how on single components development and successively to the integration of the components for demonstrating the feasibility of a portable unit power system. The background on electrodes and membrane electrode assembling [7–9], on the materials development, design, test facility and test protocols has led to the realisation and testing of a 15 W air breathing hydrogen fuel cell stack (PEFC) operating at room temperature for portable application and to the realisation of the compact and integrated system. In this paper, the design, manufacturing and performance of the passive air breathing hydrogen fuel cell stack is reported and compared to a self-sufficient system able to power a portable DVD player. The realised mini power unit has a rated power of 12 W and has shown to work for 100 h with several cycle test of 3 h simulating a DVD player working.

2. Experimental

2.1. Stack design and test

An air-breathing 10 cells PEFC stack was designed, manufactured and tested [10]. The stack was designed starting from the laboratory results obtained with an air breathing single cell (reference cell). Because of the parasitic losses introduced by a not uniform internal distribution of reactants inside the stack, an increase of electrical resistance related to the serial cells connection, and so on an energy loss of about 10% was calculated passing from reference single cell to the stack.

* Corresponding author. Tel.: +39 090624294; fax: +39 090624247.
E-mail address: urbani@itae.cnr.it (F. Urbani).

0378-7753/$ – see front matter
doi:10.1016/j.jpowsour.2007.03.049

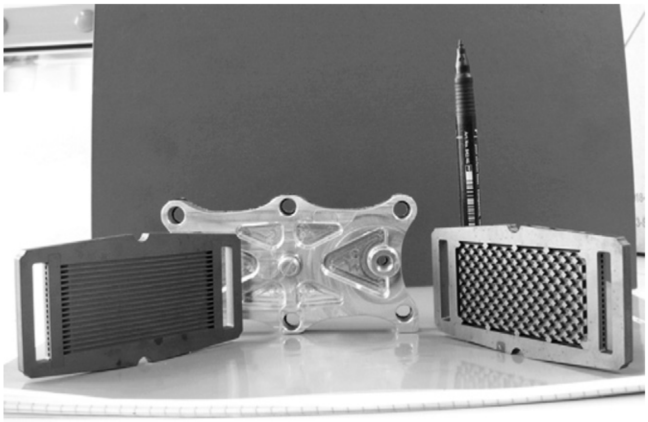

Fig. 1. Bipolar plates (anode on the left and cathode on the right) and end plate of the air breathing fuel cell stack.

The bipolar plates were designed using a CAD/CAM software, and realised by machining 5 mm thick graphite composite (XM9612 graphite grade, SGL carbon) plates.

Parallel channels flow-path having a rectangular cross-section was adopted as flow-field for the anode side and a spot type flow-field was used at the cathode side. Eight rectangular openings (four per each side) connect the cathode side flow-field to the environment and provide oxygen to the electrode by natural convection. To obtain an uniform distribution of single cell voltage both the inlet an outlet manifolds were designed with a cross-section area of 216 mm^2 that is about 21 times greater than the total cross-section area of the overall hydrogen flow-path.

Home made three layer electrodes [7–9] with a total Pt load of 0.9 $mg\,cm^{-2}$ and Nafion® 112 were used to obtain MEAs. Gore-TEX® gaskets were used and integrated with MEA by hot pressing. Two 10 mm thick aluminium end plates distribute the clamping force of six 6 mm tie-rods on the bipolar plates surface, two copper plates were used as current collectors. In Fig. 1 air and hydrogen flow-fields are shown.

Stack performance (cell voltages, current and temperatures) was determined using a home made test bench in pure air breathing and forced air operating mode with two different torque values (1.5 and 3.0 Nm). The entire test set was conducted using an hydrogen over pressure of about 22 kPa.

2.2. Power unit realisation and test

The power unit design was addressed to the simplicity [11]. The CAD model in Fig. 2a shows the layout and the components disposition inside the box. Overall box dimensions are 205 mm × 130 mm × 280 mm. The stack was directly coupled to an home made dc–dc converter (able to stabilise the output to 11.3 V. A little fan (12 V–1.5 W), to circulating the air inside the box, was powered from the stack, the fan run when supply (stack) voltage is greater than 4 V. A 40 hydrogen litres metal hydride tank (solid H) with heat exchange fines was used for hydrogen storage. Hydrogen pressure is controlled by a pressure regulator placed at the stack inlet, an on–off manual valve was used to start up and shut down the stack. The fan had the purpose to maintain a constant air circulation inside the box to

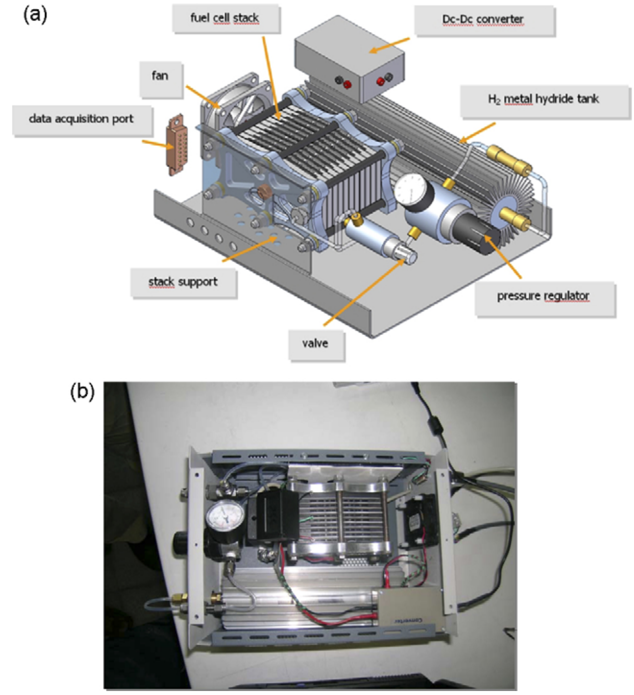

Fig. 2. (a) Layout of the mini power unit box assembling and (b) mini power unit overview.

stabilise the stack temperature and avoid the humidity condensation on the metal hydride tank. During discharge the metal hydride tank needs heat and then acts as an internal cooler for the box. For experimental purpose the box was equipped with a digital gas flow meter and some voltage sense cables to acquire voltage, current and hydrogen flow during the tests. Picture in Fig. 2b shows an overview of the assembled box.

Considering that the dc output of the air breathing stack may vary from 4.5 V under maximum load, to 8.5 V with no load, power conditioning and dc voltage stabilisation is indispensable for supplying any consumer electronic equipment. Commercial dc–dc converters, suited for operating in these particular ranges of power and voltage, are somewhat difficult to find. Therefore, it was designed and assembled an electronic unit specific for this fuel cell generator system; considering also the portable use for which the power unit was intended, small dimensions, light weight and high efficiency were considered relevant goals. The realised dc–dc converter can operate with an input voltage from 2.2 to 12 V and its maximum output voltage is 17.5 V. A power efficiency of 92% at 4.2 V input and 0.5 A output was found. dc output voltage variation was within ±0.1 V when load current increased from 0.05 to 0.5 A. ac output voltage noise was less than 20 mV (RMS value, dc to 20 MHz frequency range, measured by means of a Tektronix TDS 350 digital storage oscilloscope). The final device dimensions, shown in Fig. 3, are 45 mm width, 35 mm height and 10 g weight.

3. Results and discussion

In Fig. 4 the *I–V* curves obtained on a 10 cells stack are reported and compared to the reference cell. The stack operating with natural convection has given a maximum power density of

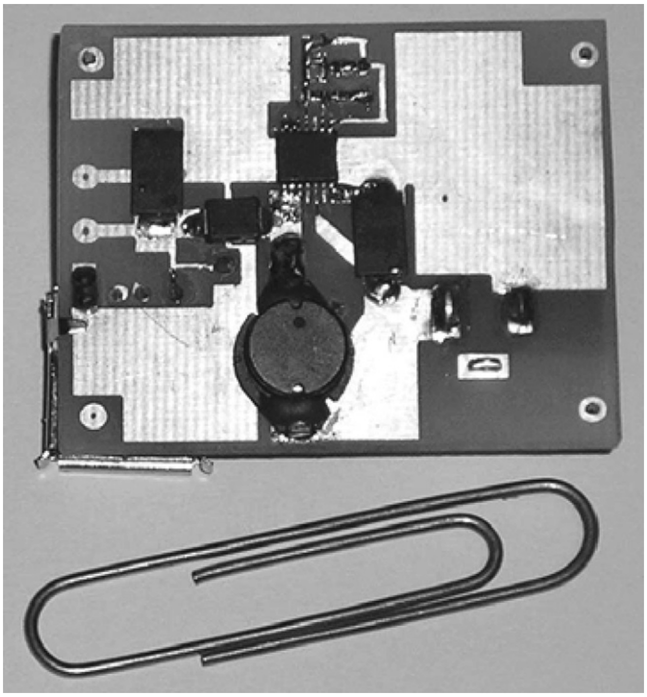

Fig. 3. View of the final circuit.

48.20 mW cm^{-2} at 0.68 V (70.88 mA cm^{-2}) in the *I–V* curve, showing a decrease of about 1.44% respect to the reference cell performance at the same current density, even if the curve fell down at about 70 mA cm^{-2} due to the oxygen starvation induced by the cathode flow field geometry that is unable to spontaneously supply a correct amount of the reactant at higher current densities. At the fixed current density of 80 mA cm^{-2} a decrease of 17.10% instead of the predicted 10% was observed. This phenomenon was overcame using a recirculation fan that allows a better air convection at the cathode side. In this case the reference and stack average voltage curves are comparable at higher current density also. In fact, in these conditions the stack was able to give a maximum power density of 82 mW cm^{-2} at 0.43 V, and at the current density of 80 mA cm^{-2} an average single cell stack voltage of 0.64 V against 0.684 of the reference cell was obtained.

These results were obtained with the clamping force on tie rods at 1.5 Nm torque. Increasing the clamping force an increase in stack output was observed. The effect of clamping force rise up is depicted in Fig. 5, where the comparison between *I* and *V* curves obtained with a low torque (1.5 Nm, dashed line) and an high torque (3.0 Nm, full line) is reported. Both of curves were obtained with the fan above described.

Imposing the low torque a maximum power of 82.27 mW cm^{-2} at 4,33 V (190 mA cm^{-2}) was obtained. Increasing the torque to the higher value a maximum power density of 124.80 mW cm^{-2} at 4,80 V (260 mA cm^{-2}) was achieved due to the stack resistance reduction. Nevertheless, the high torque application caused the damage of some bipolar plates after few test days, this event was attributed to a not correct distribution of pressure on the bipolar plates surface, due to a probable misalignment of stack components. To overcome this problem new reinforced bipolar plates are under development.

All measurements were made with the laboratory room at about 25 ± 1 °C, the laboratory relative humidity was of about 45–55% (periodically checked on the laboratory hygrometer).

Starting from these results, the stack was assembled with a metal hydride tank for H_2 supply, the dc–dc converter for power output control and a fan for stack cooling. The realised unit was tested coupling it to a portable DVD player. The cycle test is composed by

- start-up (few seconds),
- DVD player switch-on, DVD play,
- pause (from few minutes to 1 h),
- DVD play,
- DVD player switch off and shut down, and
- Tests were repeated up to the discharge of the hydride tank.

Fig. 6 shows data extracted from a cycle test. Data are acquired directly on the stack. On the left is clearly visible the unit start-up. The increase in performance of the stack in the first

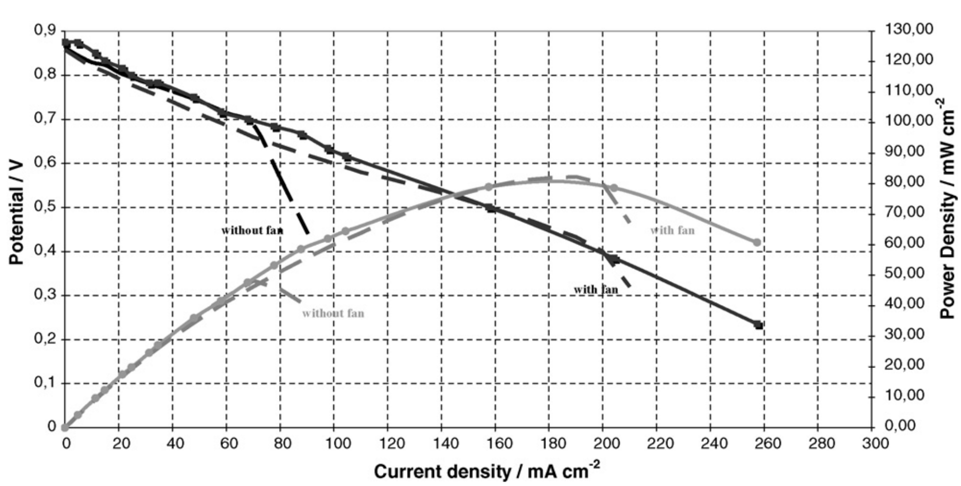

Fig. 4. Reference cell (full line) vs. stack (dashed lines) comparison in natural convection and forced configuration.

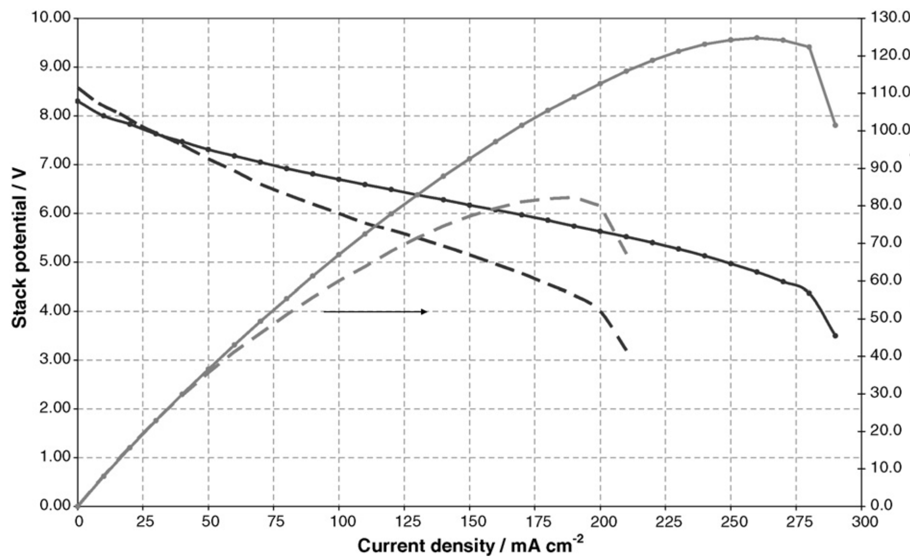

Fig. 5. Effect of the clamping force.

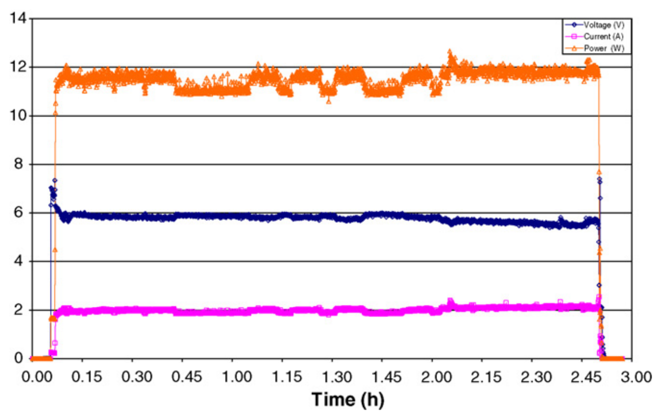

Fig. 6. Test of power unit supplying a DVD player.

10 min was related to the stack temperature increase from room to about 30 °C. Changes in power request by DVD player are followed by change in stack voltage and current output without sensible instability.

During the last part of the test a voltage decrease was observed, due to an increase in stack temperature. Nevertheless, few minutes of DVD player stop was sufficient to restore a good stack output.

Test was repeated weekly and the unit has reached about 100 h of test without sensitive losses in performance.

4. Conclusions

A 15 W nominal power (20 W peak) air breathing polymer electrolyte stack designed and manufactured at the CNR-ITAE was assembled to realise a 12 W Mini power unit for portable application. Home made electrodes and bipolar plates design were used for the stack assembling, and a miniaturised dc–dc converter was realised for the integration of the unit. The system has been connected to a portable DVD player and tested with cycles simulating a DVD player. Up today it has reached about 100 h of work without maintenance. Improvements in mechanical and thermal management, hydrogen storage and stack sealing are necessary for a further miniaturisation of the system.

References

[1] H. Voss, J. Huff, J. Power Sources 65 (1997) 155–158.

[2] K. Tüber, M. Zobel, H. Schmidt, C. Hebling, J. Power Sources 122 (2003) 1–8.

[3] M. Oszcipok, M. Zedda, J. Hesselmann, M. Huppmann, M. Wodrich, M. Junghardt, C. Hebling, J. Power Sources 157 (2006) 666–673.

[4] R.K. Ramana, S.K. Prashant, A.K. Shukla, J. Power Sources 162 (2006) 1073–1076.

[5] H.-P. Chang, C.-L. Chou, Y.-S. Chen, T.-I. Hou, B.-J. Weng, Inter. J. Hydr. Energy 32 (2007) 316–322.

[6] D. Chu, R. Jiang, J. Power Sources 83 (1999) 128–133.

[7] E. Passalacqua, G. Squadrito, F. Lufrano, A. Patti, L. Giorgi, J. Appl. Electrochem. 31 (2001) 449–454.

[8] F. Lufrano, E. Passalacqua, G. Squadrito, A. Patti, L. Giorgi, J. Appl. Electrochem. 29 (1999) 445–448.

[9] E. Passalacqua, G. Squadrito, F. Lufrano, A. Patti, L. Giorgi, Electrochim. Acta 43 (24) (1998) 3665–3736.

[10] G. Squadrito, O. Barbera, G. Giacoppo, F. Urbani, E. Passalacqua, Proceedings of the 16th World Hydrogen Energy Conference S20-294, Lyon, France, 13–16 June, 2006, pp. 1–7.

[11] G. Squadrito, O. Barbera, G. Giacoppo, F. Urbani, E. Passalacqua, Fuel Cell Seminar 2006, in: Extended Abstracts for Poster Presentations, Honolulu, Hawaii, 13–17 November, 2006.