Journal of Power Sources 196 (2011) 1030–1035

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Experimental analysis of pulsing techniques in a proton exchange fuel cell

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ARTICLE INFO

Article history:
Received 16 July 2010
Received in revised form 3 August 2010
Accepted 5 August 2010
Available online 24 August 2010

Keywords:
PEMFC
Pulsing

ABSTRACT

The purpose of this study is to investigate the impact of pulsing reactant flows on the performance of a PEMFC at low current density. This study considers a full range of pulsing flows and their effect in voltage over time. The factors evaluated were voltage, pressure, and flow rates of each reactant flow over time. A specific current density was set for the experiments. The experiments were performed at lower flow rates and temperatures of reactants than in standard operating conditions. The experiments used constant temperature of reactants as well as constant relative humidity. Comparison made between continuous flow and several sets of pulsing flows for hydrogen and air were developed. Pulsing of reactants opens an opportunity as a practical water management procedure. In addition, this technique helps extending performance range on PEMFC when a limited amount of reactants is supplied. The data collected was presented in graphical form.

1. Introduction

Proton exchange membrane fuel cells (PEMFC) are considered a clean and alternative form of energy conversion for stationary as well as mobile applications. Issues regarding hydrogen supply as well as water management are still significant factors in PEMFC design. An early model of water generation and its behavior regarding PEMFC channels was discussed by Basu [1]. Further studies of two-phase flow and blockage and their correlation with pressure drop in PEMFC were analyzed by Matamoros [2] and Appleby [3]. Experimental results have also demonstrated that under low-flow conditions, water accumulation within PEMFC channels due to flooding occurs [4,5]. Bear [6] studied water accumulation in channels and its correlation with pressure during imbibition and drainage process. Zhang [7] in 2008 presented a predictive control model of water management in PEMFC using the Simulink® software. It shows a complex method to control humidity and to avoid water build-up in real time. Lu [8] shows a study of flow distribution, pressure drop, and two-phase flow pattern in gas channels. This study shows the influence of multiple airflow rates and its relationship with water build-up in cathode channels. In addition, Yu [9] shows that purging operations are an effective way to remove accumulated liquid water in the anode of PEMFCs. Furthermore, the experimental results presented in this paper investigate the impact of pulsing reactant flows on the performance of a PEMFC.

2. Experimental system

This paper examines the supply of reactants under pulsing conditions varying from continuous flow to 5 Hz and their effect in voltage over time. The experiments were carried out using an EcoFC-6 fuel cell. This planar PEMFC has an active surface area of 14.5 cm^2 with a serpentine channel distribution. Interior serpentine gas channels are 1 mm in diameter. Its maximum output voltage is 0.9 V per cell and has six cells. Design operating conditions for this PEMFC are a gas pressure of 13.97×10^4 Pa for H_2 and 15.40×10^4 Pa for O_2. Acceptable ambient temperatures for operation are between 0 and 50 °C. The optimal working conditions for achieving maximum output are 99.99% purity of H_2 and O_2 gases, 100% humidification, and stack temperature 80 °C. This fuel cell was operated at 30 °C and 100% humidification for both air and hydrogen. Gases concentrations were maintained to 1 M. The pulsing amplitude range for each reactant was of 1 l min^{-1} and 25 psi. A 1 Ω resistance with 24 W maximum capacity was used as constant load. The experiments were developed using lower operating flow rates and temperatures of reactants than design operating conditions. Current density was kept constant at 0.024 for the experiments.

The modular experimental setup based on electrical transducers and analog inputs DAQ were developed. These devices allowed testing of multiple arrays of pulsing flows for air and hydrogen

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0378-7753/$ – see front matter
doi:10.1016/j.jpowsour.2010.08.044

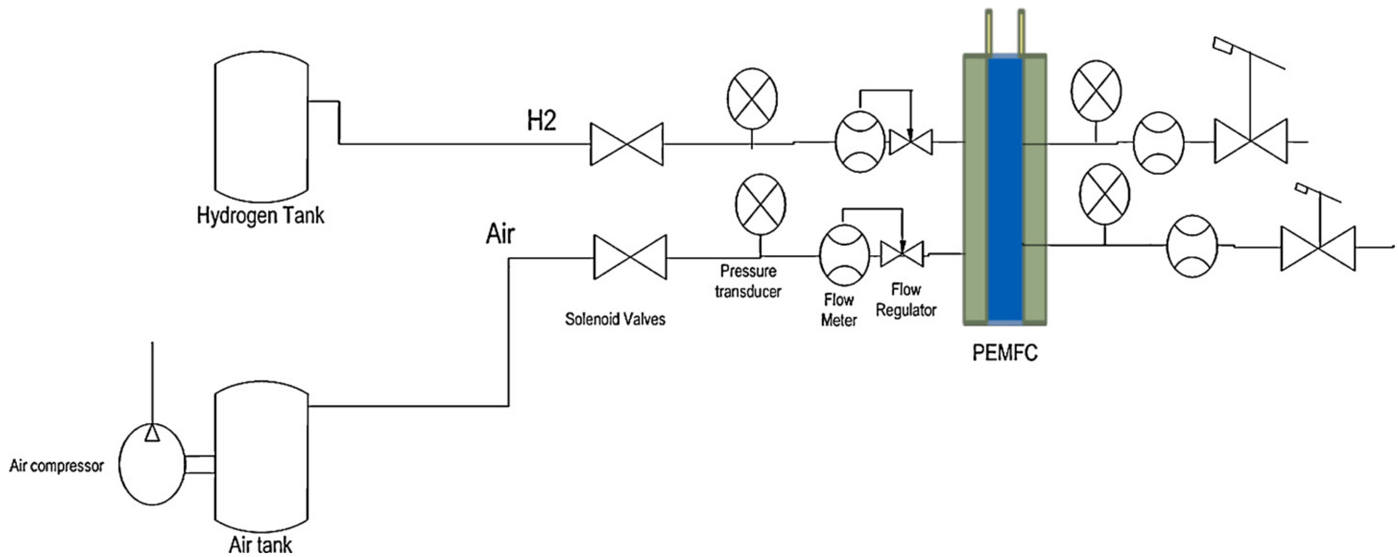

Fig. 1. Hardware schematic PEMFC.

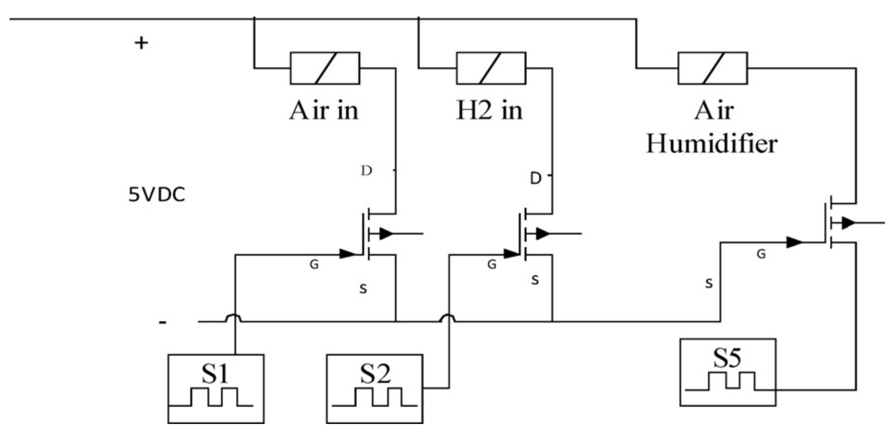

Fig. 2. Electrical diagram transistors connection.

inlets and their effect on power performance over time. Fig. 1 shows a schematic of the hardware and connections made for the PEMFC.

Electrical hardware setup consisted of mosfets transistors in conjunction with DC electro pneumatic solenoid valves. In order to produce pulsing flow, two solenoids were used. A transistor circuit connection was implemented to control solenoids pulsing frequencies. Two solenoids were connected to each inlet. A third solenoid was used for manual pulsing of water into the fuel cell as hydration membrane method. Pulsing signals were generated by mosfets transistors used as on–off switches. Fig. 2 shows the electrical diagram for the transistors connection.

Hardware setup consisted hydrogen lines of solid stainless steel tubing with 6.35 mm OD and maximum withstanding pressure of 24 MPa. Air connections were made of solid stainless steel tubing, flexible stainless steel tubing, and transparent flexible plastic tubing. Fittings and connections were pressure rated for standard high-pressure pneumatic applications. The complete hardware mounting was made using standard 6.35 mm OD pneumatic pipe systems. A type II hydrogen steel tank Praxair with maximum withstanding pressure of 2 MPa was used for hydrogen supply. An air supply with maximum pressure flow rate of 517.1 kPa and maximum flow rate of 501 $cm^3 s^{-1}$ was used for the experiments. An electronic setup was also developed by installing a data acquisition/control system capable of varying pulsing frequencies for both inlets independently.

3. Performance under continuous flow of reactants

Fig. 3 shows the performance of the EcoFC-6 under constant flow of reactants. The factors evaluated were voltage, pressure, and flow rates of reactants flow over time. Temperature and relative humidity are constants. This figure shows that the voltage performance of the PEMFC under low flow rates can be separated in three stages: activation, optimal, and flooding conditions. In addition, it shows pressures readings at the inlet are gradually increasing while the pressure readings at the outlet gradually decrease, verifying previous investigations concerning of over hydration and blockage [8]. This increase in differential pressure indicates an internal flooding of the fuel cell and which brings a complete loss of power under the supply of reactants selected.

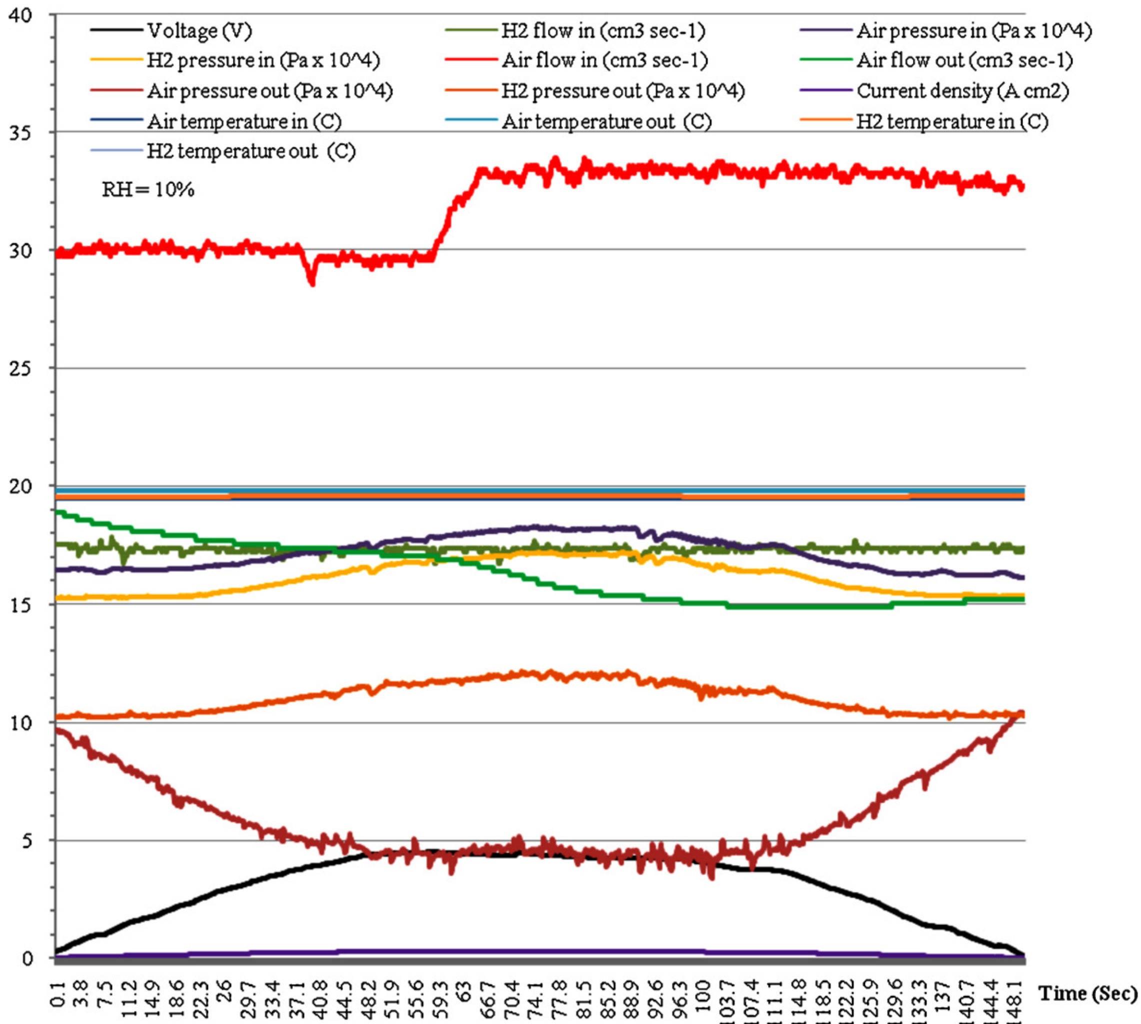

Fig. 3. Power under continuous for EcoFC-6.

4. Pulsing of flow rates for both reactants independently under selected frequency signals

Pulsing flow rates of reactants under selected frequencies were independently carried out for hydrogen and air. The selected pulsing frequencies went from continuous to 5 Hz. Flow rates and pressures of reactant inlets and outlets were monitored and display. Samplings rate of 0.1 s was used. Data collection was carried out after activation and under optimal conditions for 30 s. Data recording for each pulsing experiment was individually made. Temperatures H_2 in/out as well as RH have been explicitly stated for the experiments on each chart (current density = 0.024 A cm^{-2}, Temp. air in = 19.1 °C, Temp. air out = 20.1 °C, Temp. hydrogen in = 20.2 °C, Temp. hydrogen out = 20.3 °C, and RH = 10% for all experiments). Table 1 summarizes the experiments performed.

Graphical results showing the effect of pulsing are displayed in Fig. 4. These figures show voltage spikes starting from 5 to 0.05 Hz of hydrogen flow rate pulsing. Voltages over time increase with decreasing frequencies. At 5 Hz, the voltage behaves almost like under continuous flow. Voltage spikes become noticeable starting at 2.5 Hz and below. Short time durations of high levels hydrogen due to pulsing at frequencies below 0.2 Hz produces elevated voltage spikes.

Air pulsing flow experiments have been also conducted. Fig. 5 shows graphical results of air pulsing from continuous flow to 5 Hz. Fig. 5 shows voltage spikes starting to be noticeable at levels lower than 3.3 Hz. Values of pressures and flow rate for both reactants are also displayed. Under the current density studied 0.03 A cm^{-2}, the variations of frequencies have demonstrated a direct correlation between the pulsing rate and performance. Low-pulsing frequencies increase the differential potential pressure.

Table 1
Pulsing conditions settings.

#	Pulsing H_2 (Hz)	Pulsing air (Hz)
a	Continuous flow	Continuous flow
b	5	5
c	3.3	3.3
d	2.5	2.5
e	2	2
f	1	1
g	0.66	0.66
h	0.5	0.5
i	0.33	0.33
j	0.2	0.2
k	0.1	0.1
l	0.05	0.05

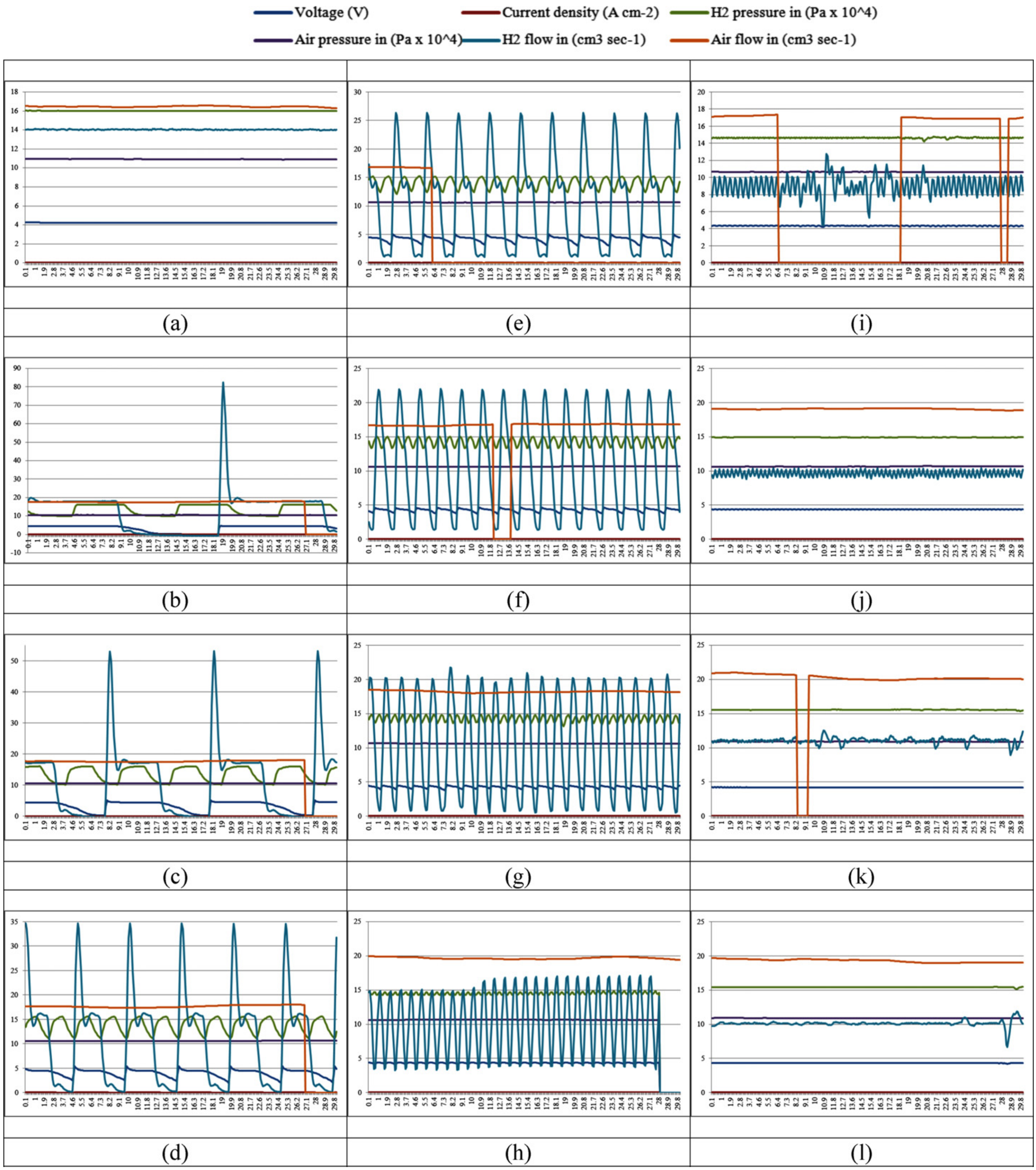

Fig. 4. Experimental results of pulsing of hydrogen flow inlet over time. (a) Continuous flow of reactants, (b) 0.05 Hz pulsing hydrogen, (c) 0.1 Hz pulsing hydrogen, (d) 0.2 Hz pulsing hydrogen, (e) 0.33 Hz pulsing hydrogen, (f) 0.5 Hz pulsing hydrogen, (g) 0.66 Hz pulsing hydrogen, (h) 1 Hz pulsing hydrogen, (i) 2 Hz pulsing hydrogen, (j) 2.5 Hz pulsing hydrogen, (k) 3.3 Hz pulsing hydrogen, (l) 5 Hz pulsing hydrogen. RH = 10% Temp. air in = 19.1 °C, Temp. air out = 20.1 °C, Temp. hydrogen in = 20.2 °C, Temp. hydrogen out = 20.3 °C.

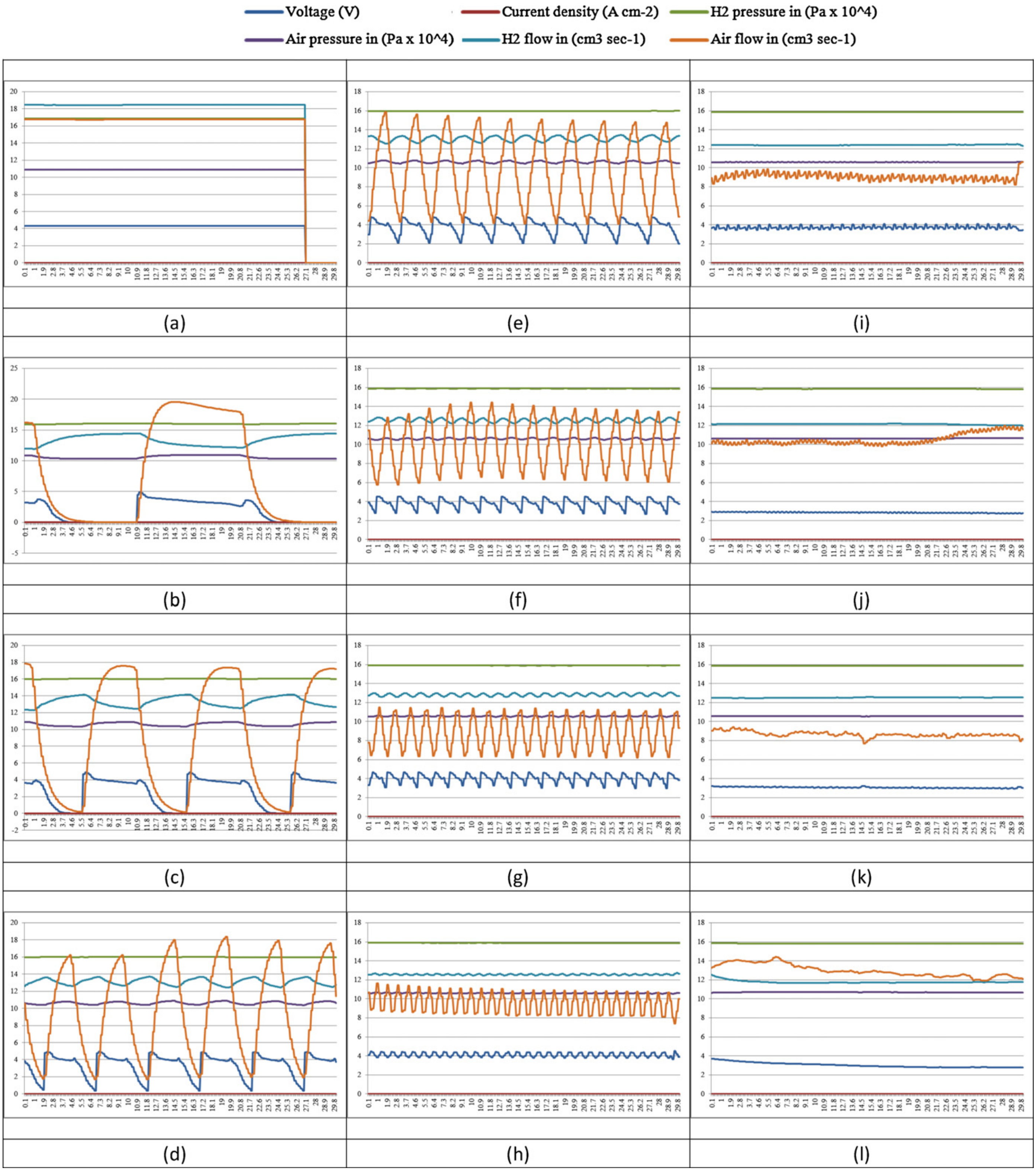

Fig. 5. Experimental results of pulsing of air flow inlet over time. (a) Continuous flow of reactants, (b) 0.05 Hz pulsing hydrogen, (c) 0.1 Hz pulsing hydrogen, (d) 0.2 Hz pulsing hydrogen, (e) 0.33 Hz pulsing hydrogen, (f) 0.5 Hz pulsing hydrogen, (g) 0.66 Hz pulsing hydrogen, (h) 1 Hz pulsing hydrogen, (i) 2 Hz pulsing hydrogen, (j) 2.5 Hz pulsing hydrogen, (k) 3.3 Hz pulsing hydrogen, (l) 5 Hz pulsing hydrogen. RH = 10% Temp. air in = 12.1 °C, Temp. air out = 20.3 °C, Temp. hydrogen in = 20.3 °C, Temp. hydrogen out = 20.5 °C.

5. Concluding remarks

An evaluation of power performance on a PEMFC operating with pulsing reactant flows has been conducted. Based on the experimental results obtained, the following conclusions can be made:

- When compared with continuous flows conditions, the results have demonstrated that pulsing flows at selected frequencies yields to water removal and consequently improved power performance.

- Under the flow conditions shown, power spikes can go above 20% over operating power during continuous flow conditions.
- Results of differential pressures of reactants between inlets and exhausts decreasing with pulsing compared with continuous flows.
- Higher power spikes take place at low frequencies, specifically at 1 Hz or below.
- Under floating conditions, a small PEMFC can operate small loads while pulsing.
- Small electronics applications can benefit with pulsing of reactants as a method to temporally increase power and prolong the operating time.

References

[1] S. Basu, Recent Trends in Fuel Cell Science and Technology, Springer, 2007.
[2] J.P. Owejan, et al., Journal of Power Sources 171 (September (2)) (2007) 626–633.
[3] L. Matamoros, D. Brüggemann, Journal of Power Sources 173 (November (1)) (2007) 367–374.
[4] A.J. Appleby, J. Twidell, Philosophical Transactions: Mathematical, Physical and Engineering Sciences 354 (July (1712)) (1996) 1681–1693.
[5] A. Bazylak, et al., Journal of Power Sources 185 (December (2)) (2008) 1147–1153.
[6] J. Bear, Dynamics of Fluids in Porous Media, Courier Dover Publications, 1988.
[7] F.Y. Zhang, X.G. Yang, C.Y. Wang, Journal of the Electrochemical Society 153 (2006) A225.
[8] Z. Lu, et al., International Journal of Hydrogen Energy 34 (May (8)) (2009) 3445–3456.
[9] X. Yu, et al., Journal of Power Sources 188 (March (1)) (2009) 163–169.