European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality (ICREPQ'10)
Granada (Spain), 23th to 25th March, 2010

Performance Analysis of a PEM Fuel Cell

J.I. San Martín[1], I. Zamora[2], J.J. San Martín[1] V. Aperribay[1], P. Eguía[2]

Department of Electrical Engineering - University of the Basque Country
[1] Escuela Universitaria de Ingeniería Técnica Industrial de Eibar
Avda. Otaola, 29, 20600 Eibar (Spain) – e_mail: iepsadij@sb.ehu.es
[2] Escuela Técnica Superior de Ingeniería de Bilbao
Alda. Urquijo s/n, 48013 Bilbao (Spain) – e_mail: inmaculada.zamora@ehu.es

Abstract. In this paper, both a theoretical and an experimental study of the dynamic performance of a commercial fuel cell are described. The analysis has been focused in the start up and shutdown processes because they allow analysing the influence of different parameters. In this sense, the evolution of the stack and the environment temperatures can be observed, which allows measuring the heat released by the fuel cell.. Finally, the graphics associated with the variation of the stack voltage and current, make possible to obtain the characteristic equations of these fuel cell systems, in order to provide power for auxiliary devices when the battery is not operating.

Key words

Fuel cell start up, Fuel cell shutdown, Microgrids.

1. Introduction

Electric market liberalization and environmental conditions configure a future guided to energy diversification. In this scenario, fuel cells are devices where chemical reaction energy becomes in electricity without combustion. Their high efficiency, silent character, low emission of pollutants and flexibility with the use of fuels can be highlighted. They use hydrogen as fuel, being transformed directly into electrical energy in a similar process as in conventional batteries. Hydrogen is not in free form in nature, but appears being part of other fuels like natural gas, methane, propane, ethanol, etc., from where it can be extracted to be used in the fuel cell. Additionally, hydrogen production with renewable sources and its later use in fuel cells facilitates a clean energy source to which a brilliant future is foreseen.

Moreover, because of the complexity of the processes and the high number of devices in fuel cells, the time constant is in the range of several seconds and not in the range of micro or milliseconds. Additionally, the nominal power of fuel cells is from some W up to several MW, for portable and stationary units [1]. Also, they can work at different pressures and temperatures, which vary from the atmospheric pressure up to 100 times its value and from 20 up to 1000ºC, respectively [2]. In this context, fuel cells present numerous characteristics that grant them a promising future. Thus, their characteristics favour their integration into Distributed Generation systems, Trigeneration and Hybrid Technologies [4-5], as well as in the design of isolated or interconnected Electric Microgrids [3]-[6].

This paper presents the experimental results obtained during the start up and shutdown of the commercial fuel cell Nexa Power Module (Ballard Power Systems, Inc.).

2. PEMFC – Proton Exchange Membrane Fuel Cell

A PEM fuel cell is composed of an active layer, a diffuser layer and the terminals of the anode, the cathode and the membrane [7]. The overall process that takes place is represented by (1).

$$2H_2 + O_2 \rightarrow 2H_2O + heat + electrical\ energy \qquad (1)$$

The exit voltage of a simple cell can be represented as expressed in (2) [8]:

$$v_{FC} = E_{NERNST} - v_{act} - v_{ohmic} - v_{con} \qquad (2)$$

where, E_{NERNST} is the thermodynamic potential, and v_{act}, v_{ohmic} and v_{con} are the activation, ohmic and concentration overpotential, respectively.

In relation to the reversible voltage of the cell, the value of E_{NERNST} [9] is given by (3):

$$E_{NERNST} = \frac{\Delta G}{2F} + \frac{\Delta S}{2F}(T - T_{ref}) + \frac{RT}{2F}\left[Ln(P_{H_2}) + \frac{1}{2}Ln(P_{O_2})\right] \qquad (3)$$

where ΔG is the change in Gibbs free energy *(J/mol)*; F the Faraday constant; ΔS the change in entropy *(J/mol)*; R the universal gas constant; and P_{H2} and P_{O2} the partial pressures of hydrogen and oxygen (atm), respectively. T is the fuel cell operating temperature (K), and T_{ref} the reference temperature. Equation (3) can be simplified by using standard values for ΔG, ΔS and T_{ref} [10].

$$E_{NERNST} = 1.229 - 0.85 \cdot 10^{-3}(T - 298.15)$$
$$+4.31 \cdot 10^{-5} \cdot T\left[Ln(P_{H_2}) + \frac{1}{2}Ln(P_{O_2})\right] \quad (4)$$

3. Experimental results

In this section, the experimental results, obtained in laboratory tests of an electrical micro-grid fed with a fuel cell, are presented. The experimental micro-grid is installed in a laboratory of the Department of Electrical Engineering of the University of the Basque Country. The test bench has been configured to analyse the behaviour of fuel cells in the start up and shutdown processes. Following, a set of graphics are presented, which allow checking the values of the most significant parameters during this start up process of the fuel cell system, such as: stack temperature, ambient temperature, battery voltage, fan and compressor working cycles, hydrogen and air flow, fuel cell stack voltage, current and power, and cell voltage cheker.

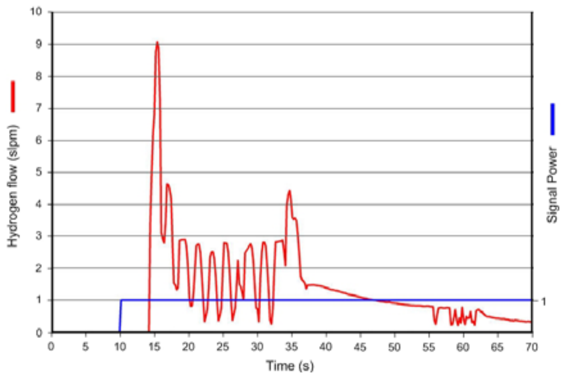

Fig.1. Flow rate of hydrogen consumed

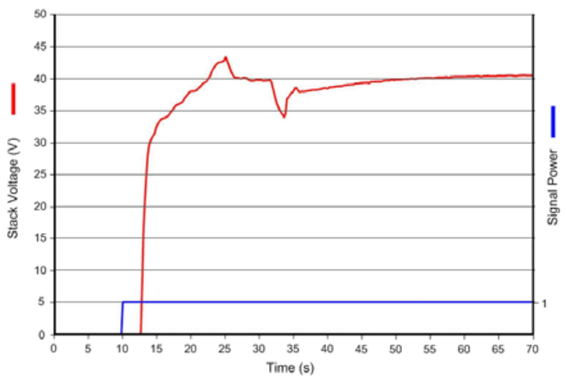

Fig.2. Fuel cell stack voltage

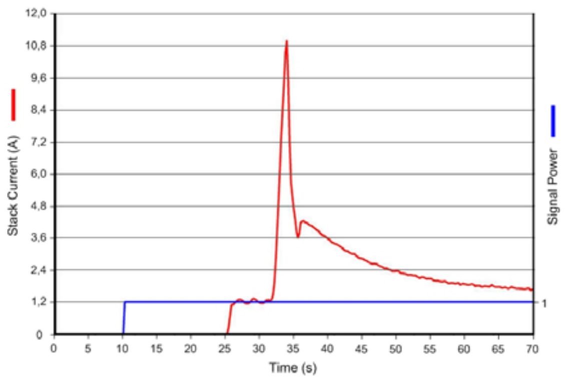

Fig. 3. Fuel cell stack current

4. Conclusions

This paper has presented the main characteristics of the start up and shutdown processes of a commercial fuel cell. In this sense, different tests have been developed in an electrical micro-grid fed with the fuel cell, where measurements of different parameters have been taken.

Thus, the evolution of the fuel cell stack and ambient temperatures has been presented. Regarding the measurements of the oxygen concentration, these values allow knowing the amount of oxygen that is needed to maintain the electrochemical reaction in the cathode of the fuel cell. Considering this aspect, graphics that allow analysing the behaviour of the air compressor are included. Besides, this fuel cell system has a battery that provides power for auxiliary during the start up. In this sense, data are provided to detect the transition between different states of operation of the battery.

Finally, data concerning consumed hydrogen and various electrical signals from the cell stack and purge sensor are included.

Acknowledgement

The work presented in this paper has been carried out by the research team of Project ENE2006-15700-CO2-02/CON, supported by the Ministry of Education and Science of Spain.

References

[1] M. Farooque, H.C. Maru, “Fuel Cells: The clean and efficient power generators”, Proceedings of the IEEE, Vol.89, Issue 12, pp. 1819-1829, 2001.

[2] W.L. Hughes, “Comments on the hydrogen fuel cell as a competitive energy source”, Proceedings of the Power Engineering Society Summer Meeting IEEE, Vol.1, pp. 726-730, 2001.

[3] K. Rajashekara, “Hybrid Fuel Cells Strategies for Clean Power Generation”, IEEE Transactions on Industry, Vol.41, No.3, 2005.

[4] I. Pilatowsky, R.J. Romero, C.A. Isaza, S.A. Gamboa, W. Rivera, P.J. Sebastian, J. Moreira, “Simulation of an Air Conditioning Absorption Refrigeration System in a Cogeneration Process Combining a Proton Exchange Membrane Fuel Cell”, International Journal of Hydrogen Energy, 2007.

[5] T.W. Song, J.L. Sohn, J.H. Kim, S.T. Ro, K. Suzuki, “Performance analysis of a tubular solid oxide fuell cell/microgas turbine hybrid power system based on a quasi-two dimensional model”, Journal of Power Sources, 2004.

[6] I. Zamora, J.I. San Martín, A.J. Mazón, J.J. San Martín, V. Aperribay, “Emergent Technologies in Electrical Microgeneration”. International Journal of Emerging Electric Power Systems, Vol.3, Issue 2, Article 1092, pp. 1-28, 2005.

[7] M. Rubio, A. Urquia, L. González, D. Guinea, S. Dormido, “Fuel Cell Lib-A Modelica Library for Modeling of Fuel Cell”, Proceedings of the 4th International Modelica Conference pp. 75-83, 2005.

[8] J.M. Correa, F.A. Farret, L.N. Canha, “An analysis of the dynamic performance of PEM fuel cells using an electrochemical model” Proceedings IEEE, IECON´01, pp. 141-146, 2001.

[9] J.M. Correa, F.A. Farret, L.N. Canha, M.G. Simoes, “An Electrochemical-Based Fuel-Cell Model Suitable for Electrical Engineering Automation Approach” IEEE Transactions on Industrial Electronics, Vol.51, No.5, pp. 1103-1112, 2004.

[10] R.F. Mann, J.C. Amphlett, M.A.I. Hopper, H.M. Jensen, B.A. Peppley, P.R. Roberge, “Development and application of a generalized steady-state electrochemical model for a PEM Fuel Cell”, Journal Power Sources, vol.86, pp. 173-180, 2000.