Experimental thermal model of a High Temperature Fuel Cell Stack

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Keywords: High Temperature PEM fuel cell, experimental modelling, thermal model, parameter fitting

1. Introduction

High Temperature PEM Fuel Cells (HT-PEMFC), with operation temperatures in the range 120ºC-180ºC, have important advantages compared with conventional PEM Fuel Cells, that operate at temperatures below 80ºC. At their high temperatures, HT-PEMFCs have better reactions kinetics, higher CO tolerance and do not present problems with liquid water formation. Besides, heat exchanges can be designed to take profit of the heat produced by the fuel cell, making the fuel cell a Combined Heat and Power (CH&P) generator. In this case, the efficiency of the system is increased significantly. However, the HT-PEMFC technology has some drawbacks, too [1]. For instance, slower start up and accentuated degradation issues.

Fuel cells are suitable generators for micro-CH&P and they may offer significant CO_2 emissions reduction. Specifically, HT-PEMFCs present good heat exchange capabilities and null emissions if renewable energy sources are used to produce the hydrogen.

A proper heat management is necessary in order to control the fuel cell temperature, especially during start up and shut down processes. The main objective of this work is to obtain a thermal model of a HT-PEMFC based on experimental data. The model is aimed at the design of temperature controllers.

2. Fuel cell description

This work is based on an HT-PEMFC stack designed and produced by ZBT GmbH [2]. It is composed by 12 cells and works between 140ºC and 180ºC. To reach the lowest operating temperature, a heating resistance is used, and to make the temperature as uniform as possible, a fan is used. Figure 1 shows a scheme of the system. The fuel cell stack (blue), heating resistance (green) and fan (grey) are contained in a casing, which provides thermal insulation to the system. To avoid excessive heating of the system during the operation, two windows can be opened. One, W_1 is near the fan and the other, W_2 is near the fuel cell stack. When the fuel cell operates at low currents, it doesn't produce enough heat to keep its temperature at 140ºC, hence the resistance is switched on and the windows must be closed. For higher operating currents the windows W_1 and W_2 have to be opened.

In Figure 1, the flow of the air that takes place when the windows are open is shown by the blue arrows. The air flow that goes through the resistance and the fuel cell is splitted in two parts; one leaves the system due to W_2 and a small amount is recirculated through Wi. This small amount of air mixes with air at room temperature that comes from W_1 and goes to the fan, closing the cycle.

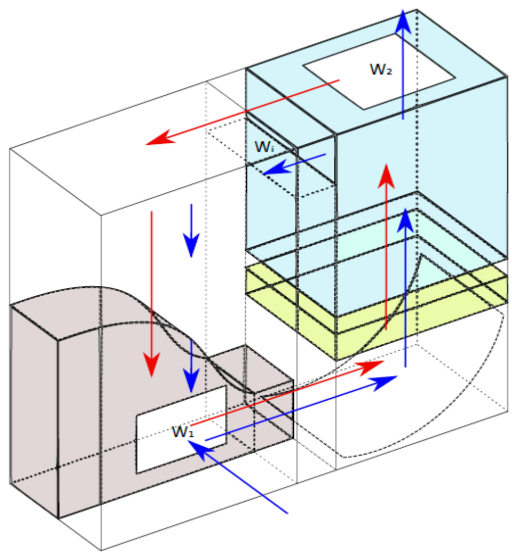

Fig. 1: Fuel cell air flows scheme

3. Model description

The thermal model proposed is a linear model that relates the stack temperature *TFC* with four different input variables: the heat given by the fan $\dot{Q}_F$, the thermal power given by the resistance $\dot{Q}_R$, the heat given by the stack $\dot{Q}_{FC}$ and the ambient temperature T_A. The corresponding expression is shown in equation 1.

$$T_{FC} = H_F(s)\dot{Q}_F + H_R(s)\dot{Q}_R + H_{FC}(s)\dot{Q}_{FC} + H_A(s)T_A \qquad (1)$$

Different experiments were performed to fit the model parameters. Since the thermal behaviour of the system was seen to change significantly depending on the windows position, two models are derived, one for the system with open windows and another for the system with closed windows.

4. Experiments description

Four experiments have been conducted, two of them (1 and 2) with the windows open and two of them (3 and 4) with the windows closed. In all cases, the current in the fuel cell has been held at zero. Experiments 1 and 3 were conducted to gather the experimental data to fit the model and experiments 2 and 4 were conducted for the model validation.

For all the experiments, at first, only the fan is switched on. When steady state is reached, the voltage on the resistance is raised, causing a new change in the temperature. Over the new steady state, a voltage waveform obtained using a PRBS signal [3] of 10% of the voltage amplitude is applied to the resistance. The sequence is repeated two more times, as shown in Figure 2. Using this signal it will be possible to see the system response to frequencies up to 10^{-2}Hz, which is more than enough in systems with a slow dynamics as the ones in which temperature is involved. The three voltage steps in experiments 1 and 3 have increasing values of 20V, 28,5V and 30V. For the validation experiments, voltages have been decreased by 10%. The values are chosen so that the stack will not reach temperatures above 180ºC.

5. Experimental results and parameter fitting

5.1 $H_A(s)$ determination

The gain of $H_A(s)$ transfer function has to be equal to one, because when the system receives no power, the temperature of the fuel cell and the room temperature have to be the same once the system reaches steady-state. About the dynamics of this system, as the experimental data in Figure 2 shows, when the temperature in the room changes, the temperature of the fuel cell changes with a dynamics that is much faster than those of the rest of the system. That is why it can be assumed that $H_A(s)$ is equal to one.

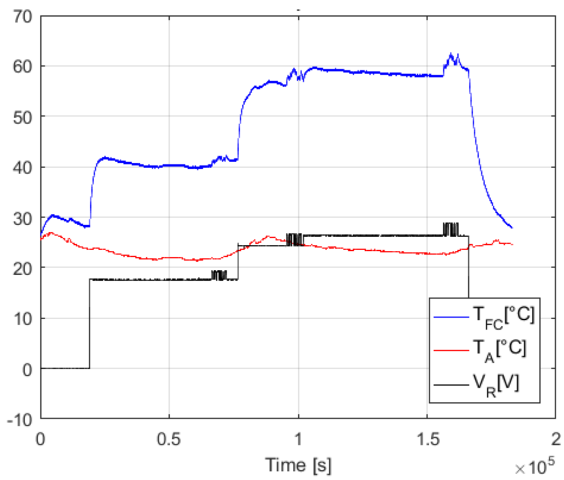

Fig. 2: Experimental data collected in experiment 3

Being fitted $H_A(s)$ to one, it is appropriate to model the difference of temperatures between the stack and the ambient instead of T_{FC}, as shown in equation 2.

$$T_{FC} - T_A = H_F(s)\dot{Q}_F + H_R(s)\dot{Q}_R + H_{FC}(s)\dot{Q}_{FC} \qquad (2)$$

5.2 $H_F(s)$ and $H_R(S)$ determination

Processing the experimental data with MATLAB System identification Toolbox, it is possible to compute the transfer functions parameters that minimize the fitting error [3]. Second order transfer functions are found to give sufficient small fitting errors and therefore they have been considered valid. Since linearity is assumed, to fit $H_F(s)$ the first part of the curves (where the resistance is off) are used, and the rest of points are used to fit $H_R(s)$.

For the system with the windows closed, the obtained transfer functions are:

$$H_F(s) = \frac{-2.35 \cdot 10^{-5}s + 5.54 \cdot 10^{-7}}{s^2 + 0.00261s + 5.79 \cdot 10^{-7}}$$

$$H_R(s) = \frac{0.00024s + 5.057 \cdot 10^{-8}}{s^2 + 0.00063s + 8.29 \cdot 10^{-8}}$$

In Figure 3, the experimental and modelled corresponding curves can be seen. The fitting is of 97,77% for the modelling data and 87,61% for the validation data.

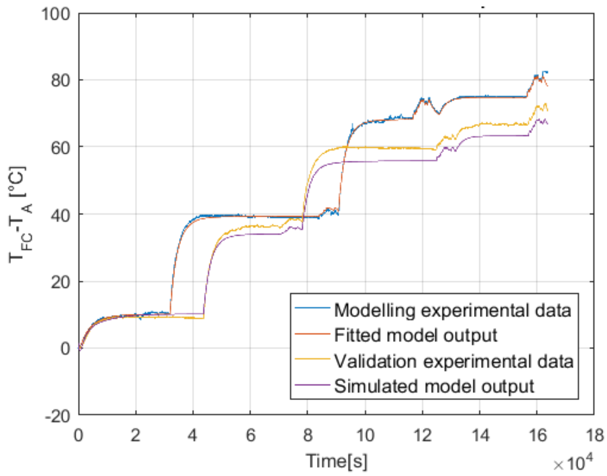

Fig. 3: Experimental and model curves (open windows)

For the system with the windows open, the fitting is of 94,96% for the modelling data and 89.82% for the validation data, and the obtained transfer functions are:

$$H_F(s) = \frac{0.00034s + 5.603 \cdot 10^{-8}}{s^2 + 0.000674s + 5.12 \cdot 10^{-8}}$$

$$H_R(s) = \frac{0.00030s + 2.328 \cdot 10^{-7}}{s^2 + 0.0018s + 6.68 \cdot 10^{-7}}$$

6. Conclusions

An experimental linear model that describes the dynamics of a HT-PEMFC stack temperature caused by the fan and the heating resistance has been obtained through parameter fitting. Second order transfer functions have shown to achieve fittings to the experimental data greater than 87% both for closed and open windows.

Acknowledgements

This work acknowledges the Spanish project with reference DPI2015-69286-C3-2-R, MINECO/FEDER.

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