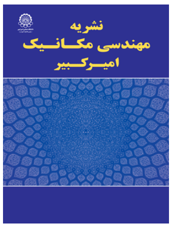

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Dynamic Modeling and Parameter Identification of Hydrogen-Oxygen PEM Fuel Cell Model with Integrated Humidifier

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ABSTRACT: Fuel cell is a type of electrochemical energy converter that converts chemical energy stored in fuel into electrical energy. Nonlinear structure, time-varying dynamics and uncertain physical parameters are the challenges of working with polymer electrolyte membrane (PEM) fuel cells. In this paper, grey box modeling and system identification of flow-through H2/O2 PEM fuel cell with three cells and integrated humidifier is investigated. First, zero-dimensional nonlinear fluidic, thermodynamic and electrochemical modeling of PEM fuel cell is performed. The fuel cell model presented in this research is Multi-Input-Single-Output type. In the following, constant parameters of the studied fuel cell are determined. The system identification process as a multi-input-single-output system is done based on the Prediction-Error minimization, using the method of Trust-Region Reflective Newton. Finally, validation of the obtained model is done with experimental data that not used in modeling. The considered PEM fuel cell was tested under different conditions of temperature, reactant gas inlet pressure and stack current, and 329,420 experimental data were obtained. According to test conditions, data was classified into 189 different modes. The results show that the average voltage error of the identified model compared to the experimental data is equal to 1.03%. Moreover, the correlation between voltage and identified model parameters has been investigated, and the results showed that correlation between voltage and the contact resistance equivalent is higher than coefficients of orifices.

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1- Introduction

A fuel cell is a type of electrochemical converter that directly converts the energy resulting from the chemical reaction of fuel into electrical energy. One of the most important and widely used types of fuel cell is the polymer electrolyte membrane fuel cell, whose unique features such as high efficiency, fast start-up, and noiselessness attract attention. Considering the complexity of polymer fuel cells, it is beneficial to have appropriate mathematical models to analyze and predict their dynamic behavior.

A model represents a physical system with a complex structure. Each model is described by various parameters that are often unknown. To ensure the accuracy of the model, these parameters should be properly identified and validated. Different models can be used, including white box model, black box model, and grey box model [1]. Analytical models, which are also known as white box models, use differential equations to simulate the behavior of the system. These models are very accurate and based on theoretical relationships. Due to the complexity of fuel cells, it is very difficult to use white box models online. Models derived directly from experiments are also known as black box models. Black box models are based on statistical data. In this model, the relationships between the inputs and outputs of the system are not based on physical equations like analytical models, but are inferred through suitable experimental data. The disadvantage of the black box model is the dependence on performing many tests for identification.

Grey box modeling can be used to take advantage of both white box and black box methods at the same time, i.e. more generalizability as well as the use of simpler relationships. Normally, in grey box models, zero-dimensional or discrete models are used due to the simplicity in calculations and less calculation time to control the system online and in real time [2].

Zeller et al. [3] developed a model based on current circuit using parameter identification method for fuel cell monitoring and control. In this model, the activation and concentration losses are modeled as two voltage sources with the opposite sign of the Nernest voltage. Hernandez et al [4] presented a model that has the ability to identify the behavior of the system in the flooded state. Their model allows studying the composition and partial pressure of gases. Carnes and Djilali [5] estimated the ion conductivity coefficients of the membrane, the current density exchange in the cathode and anode, and the oxygen penetration in the gas diffusion

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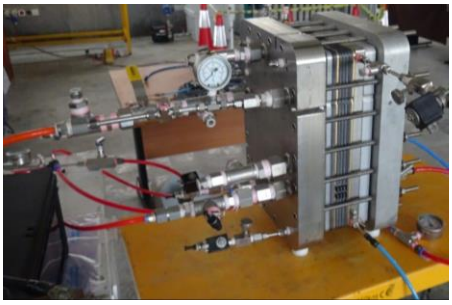

Fig. 1. The PEM fuel cell with integrated humidifier

layers and the catalyst using the constrained nonlinear least squares algorithm and the experimental data available in other researches. Barzegari *et al*. [6] modeled an dead-ended cascade polymer electrolyte membrane fuel cell with integrated humidifier and water separator. Their model was based on grey box model based on parameter identification.

By reviewing previous researches, we can consider that the modeling and identification of polymer fuel cell system and the use of models in fault identification and performance control of fuel cells have been investigated by various researchers and a lot of progress has been achieved. Multidimensional modeling of fuel cell to analyze the behavior of the system has very high computational costs and it is not possible to use these models in online applications. Therefore, the use of zero-dimensional grey box models has attracted the attention of many researchers. In this research, in order to obtain the grey box model of the polymer electrolyte membrane fuel cell stack with integrated humidifier, the nonlinear equations governing the fuel cell were obtained. The fuel cell consists of three cells, and the equations governing it, in addition to electrochemical equations, also include fluid dynamics equations and thermodynamic relationships. The unknown parameters of the model have been determined based on the parameter identification method. In order to obtain these parameters, experimental data such as pressure, temperature and current have been measured and recorded as fuel cell input and voltage as fuel cell output.

2- Modeling of Flow-through Hydrogen-Oxygen Polymer Electrolyte Membrane Fuel Cell with Integrated Humidifier

In this research, the fuel cell stack is flow-through and has three cells, where hydrogen flows on the anode side of the fuel cell and oxygen flows on the cathode side. Appropriate humidity of the reactants to minimize the risk of membrane dryness is obtained through a membrane humidifier with a serpentine flow field. Two humidifying cells is considered, each cell is used to humidify one of the dry reactant gases.

The model used for the research is zero-dimensional and includes three main parts of fluid dynamics, thermodynamics and electrochemical. In this research, the modeling of the desired polymer electrolyte membrane fuel cell is based on the following assumptions [2]:

All gases are considered to be ideal gas.

Inlet gases are completely dry and pure.

Heat distribution in all parts of the humidifier and fuel cell stack is considered to be uniform.

System Identification of the Polymer Electrolyte Membrane Fuel Cell with Integrated Humidifier

The fuel cell stack shown in Figure 1 was investigated under different conditions of temperature, gas inlet pressure, and current, and 329,420 experimental data were classified into 189 different conditions according to the test conditions.

135 modes of experimental data were used to train the model and 54 modes were also used to validate the identified model. Using experimental data, the value of unknown and unmeasurable parameters of the model is identified and model calibration is performed.

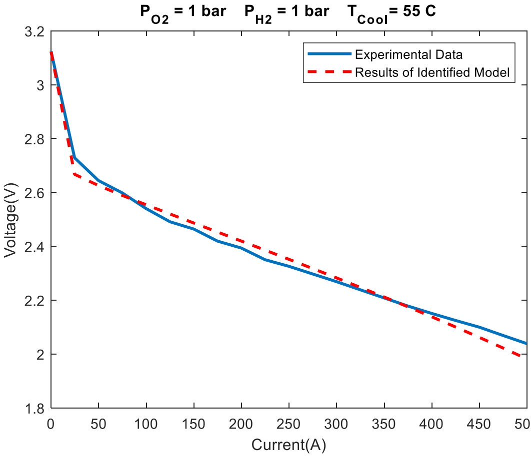

Fig. 2. Comparison of simulation results and experimental data of polarization curve

3- Results and discussion

After the system identification process, the obtained parameters are placed in the main equations and the output voltage extracted from the numerical simulation results is compared and validated with the experimental data. The average voltage error of the fuel cell model detected in 189 cases is equal to 1.03%.

In order to validate the identified fuel cell model, comparing the results of the fuel cell polarization curve obtained from this model and the experimental values, as well as the square of errors between the estimated fuel cell voltage and the experimental data are demonstrated in Figure 2 and Figure 3, respectively. As shown, the maximum square error is less than 0.4%.

4- Conclusions

In this article, gryy-box modeling and system identification of three-cell open-ended hydrogen-oxygen polymer electrolyte membrane fuel cell with integrated humidifier is investigated. The unknown parameters of the

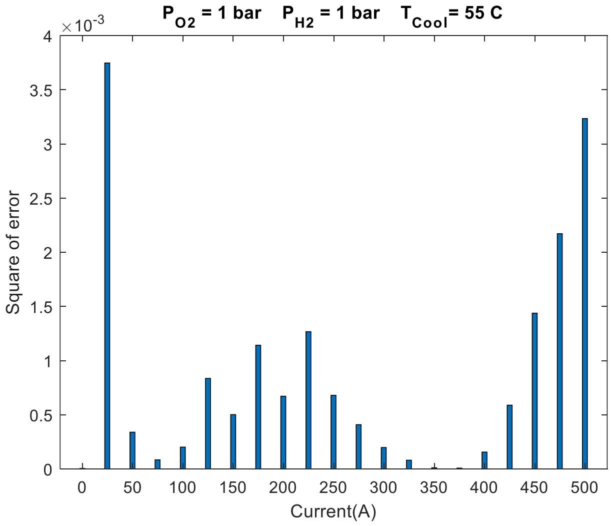

Fig. 3. Error square between estimated voltage and experimental data

studied fuel cell model were determined by using the multi input-single output parameter identification method. Finally, the validation of the obtained model has been investigated using experimental data.

References

[1] R. Petrone, Z. Zheng, D. Hissel, M.-C. Péra, C. Pianese, M. Sorrentino, M. Béchérif, N. Yousfi-Steiner, A review on model-based diagnosis methodologies for PEMFCs, International Journal of Hydrogen Energy, 38(17) (2013) 7077-7091.

[2] I. Arsie, A. Di Domenico, C. Pianese, M. Sorrentino, A multilevel approach to the energy management of an automotive polymer electrolyte membrane fuel cell system, Journal of Fuel Cell Science and Technology, 7(1) (2010).

[3] A. Zeller, O. Rallières, J. Régnier, C. Turpin, Diagnosis of a hydrogen/air fuel cell by a statistical model-based method, in: 2010 IEEE Vehicle Power and Propulsion Conference, IEEE, 2010, pp. 1-6.

[4] A. Hernandez, D. Hissel, R. Outbib, Modeling and fault diagnosis of a polymer electrolyte fuel cell using electrical equivalent analysis, IEEE Transactions on Energy Conversion, 25(1) (2009) 148-160.

[5] B. Carnes, N. Djilali, Systematic parameter estimation for PEM fuel cell models, Journal of Power Sources, 144(1) (2005) 83-93.

[6] M.M. Barzegari, M. Dardel, E. Alizadeh, A. Ramiar, Dynamic modeling and validation studies of dead-end cascade H2/O2 PEM fuel cell stack with integrated humidifier and separator, Applied energy, 177 (2016) 298-308.

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