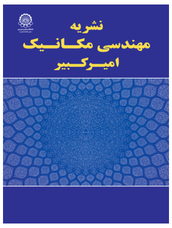

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Experimental Cathode-Anode Flooding Diagnosis of Polymer-Electrolyte Fuel Cell of Power under 300W Using Adaptive-Neuro-Fuzzy Method

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ABSTRACT: Today, due to the growing importance of polymer electrolyte membrane fuel cells in the production of clean energy, the diagnosis of this energy converter has become very important. Diagnosis can significantly increase the useful life and reliability of the fuel cell. A major part of the defects related to the polymer electrolyte membrane fuel cells is due to the disturbance of the moisture balance in them. Flooding is one of the most common defects associated with fuel cell imbalance, which is possible in both the cathode and the anode side of the cell. In previous works, the cathode has been considered as the only possible place for flooding, mainly because it is the source of water production. In this article, the anode is also considered as a possible place for this phenomenon. The method of this research is based on taking data from the stack under healthy operating conditions and trying to estimate the output parameters of stack voltage, cathode pressure drop, and anode pressure drop using related inputs using the adaptive neuro-fuzzy method. In conditions of uncertain operation in which the healthy or flooding operation of the stack is not known, comparing the deviation of the actual values of the outputs from the model with the allowable values of these deviations (0.735 [V], 0.0092 [bar] and 0.0047 [bar], respectively) can lead to determining flooding or normal conditions.

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1- Introduction

Polymer Electrolyte Membrane Fuel Cell (PEMFC) is one of the energy converters; where the reaction between hydrogen and oxygen generates electrical energy and heat. The unique feature of this type of fuel cell compared to other types is its operation at low temperature, high efficiency, and high energy density; in such a way that it can be used for transportation or stationary applications such as simultaneous generation of electricity and heat. This high efficiency reaches more than 90% by using both electric energy and heat [1] and this feature has given this converter additional capability for use in homes to generate decentralized electricity. Operation without moving parts, quietness, and no emissions are the advantages of using this cell over internal combustion engines.

Despite its many advantages, this energy converter has not yet found its expected place in commercialization. One of the important factors that prevented the expansion of the use of this fuel cell was its low reliability. This causes premature degradation of the cell and reduced performance.

Considering that more than half of the defects related to polymer membrane fuel cells are related to moisture [2], a lot of efforts have been made in the field of water management in PEMFC in recent years.

The adaptive neuro-fuzzy method is one of the powerful methods of identifying functions; which takes advantage of two powerful tools of fuzzy logic and neural network theory, and so far this method has rarely been used to estimate functions in the field of fuel cell water management. In this research, this method is used to estimate the output functions: voltage, cathode channel pressure drop, and anode channel pressure drop under normal condition. By using these functions and comparing their value with the actual value of these parameters in the system, it is possible to detect the incidence of flooding, its location, and degree of importance under the electronic load current.

2- Methodology

2- 1- Testbed description

To use the fuel cell stack, a primary testbed is available in the fuel cell laboratory of the Department of Mechanical Engineering of Amirkabir University of Technology; which has been designed and fabricated by the Iranian Space Research Center. After entering this apparatus, hydrogen and oxygen gases pass through the manual rotameter and each passes through a separate humidifier and then enters the stack. These rotameters allow manual flow adjustment. The electronic charge used in this device is designed in such a way; which allows the Fuel Cell (FC) to operate up to 800 W. The data of this testbed's sensors is transferred to the computer by

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Fig. 1. Designed and fabricated testbed in fuel cell laboratory of Mechanical Engineering Department of Amirkabir University of Technology (left side of image) besides primary testbed made by Iranian Space Research Center (right side of image)

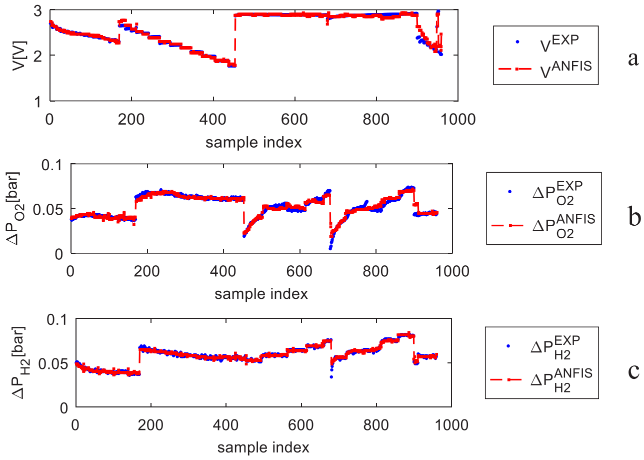

Fig. 2. Real output data (blue colored) besides ANFIS approximated outputs (red colored) in normal condition in parameters: a) Stack voltage, b) Oxygen pressure drop and C) Hydrogen pressure drop.

ICP-DAS remote I/O cards on the RS485 hardware platform.

In addition to this testbed, another testbed was designed and fabricated from scratch in this research and added to the previous testbed. This testbed allows automatic control of cathode and anode gas flow. Another function of this apparatus was to control the temperature of the water-cooled stack using deionized water. Fig. 1 shows the primary testbed next to the testbed fabricated in this study.

2- 2- Structure of adaptive neuro-fuzzy modeling

One of the methods of black box modeling of complex and chaotic nonlinear functions that, while simple and high speed of calculation, does not require much understanding of the physics of the problem, is the modeling using the adaptive neuro-fuzzy method. In this modeling, considering the *M* fuzzy rules, a fuzzy system is introduced as follows:

$$\begin{aligned} &if\ x_1\ is\ A_1^l\ and\ \ldots x_n\ is\ A_n^l\ then \\ &\boldsymbol{y}^l = \boldsymbol{c}_0^l + \boldsymbol{c}_1^l \boldsymbol{x}_1 + \boldsymbol{c}_2^l \boldsymbol{x}_2 + \ldots + \boldsymbol{c}_n^l \boldsymbol{x}_n \end{aligned} \quad (1)$$

In these rules, A_i^l s are a set of integers, *l* is an integer in the range 1 to *M*; that *M* is the number of rules. c_i^l s are also fixed and adjustable numbers so that the output of the model has the least error with the actual output data. The output of this system is calculated from Eq. (2):

$$f = \frac{\sum_{l=1}^{M} y^l \omega^l}{\sum_{l=1}^{M} \omega^l} \quad (2)$$

In which ω^l is firing strength and is calculated as follows:

$$\omega^l = \prod_{i=1}^{n} \mu_{A_i^l}(x_i) \quad (3)$$

In fact, any continuous function whose output value is between 0 and 1 can be a candidate for $\mu_{A_i^l}(x_i)$.

2- 3- Model training and validation

Among the experimental data, 70% were randomly selected to train the Adaptive Network-Based Fuzzy Inference System (ANFIS) models and 30% to test the accuracy and generalization. In the diagrams in Fig. 2, the curves of the adaptive neuro-fuzzy models are compared with the actual output curves of the system in three output parameters. It should be noted that in these diagrams, the data related to the training of models and the data related to their testing are placed next to each other.

3- Results and Discussion

After training three adaptive neuro-fuzzy models to estimate the output functions of cell voltage, cathode pressure drop, and anode pressure drop, using the data of healthy operating conditions, the experiments were repeated over a wide range of stack temperature and different reactor flows. This time, an attempt was made to identify possible flooding defects that occurred in this experiment. The output curves of these experiments, along with the ANFIS estimations of the ideal operating conditions, are shown in the diagrams of Fig. 3.

Now deviation of real values and ANFIS estimated values

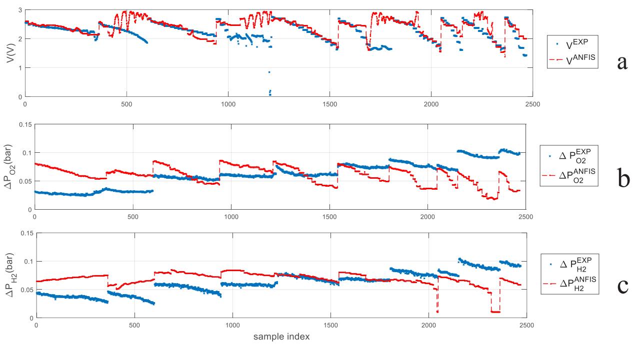

Fig. 3. Unknown condition real data (blue-colored curves) besides ANFIS approximated values in normal condition (red-colored curves) for parameters: a)Stack voltage, b) Oxygen pressure drop and c)Hydrogen pressure drop.

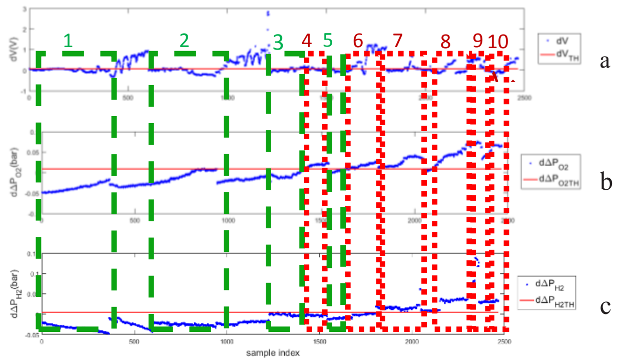

Fig. 4. Deviation parameters of outputs from ANFIS predicted values in comparison with deviation thresholds for parameters: a) Voltage, b) Cathode pressure drop and c) Anode pressure drop.

Table 1. Status of different work regions from the perspective of flooding defect

Region Number	Status
1	Normal
2	Normal
3	Normal
4	Initial cathode flooding
5	Normal
6	Cathode severe flooding
7	Initial cathode and anode flooding
8	Cathode and anode severe flooding
9	Initial cathode and anode flooding
10	Cathode and anode severe flooding

are calculated and plotted beside deviation thresholds and regions status will be identified in Fig. 4.

The status of the regions is listed in Table 1.

4- Conclusion

This paper focuses on the diagnosis of a PEMFC in a very common defect: flooding. In most previous works, only the cathode was considered as a possible location of flooding. In this paper, due to the back diffusion phenomenon, the anode has also been considered as a possible place for flooding. The method was used to estimate the output functions: voltage of the cell, the pressure drop of the cathode channel and the pressure drop of the anode channel in ideal conditions with the aid of adaptive neuro-fuzzy approximates and compare them with the current state. To do this, variables are used as input of ANFIS functions that are easy to measure. These variables are the mass flow rate of oxygen and hydrogen, the temperature of wet hydrogen and wet oxygen, electric current, and stack temperature of the cell. With these three models and the allowable deviation thresholds, the occurrence of the flooding phenomenon in the cathode and anode and its intensity can be easily detected with minimal hardware such as ARM processors.

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