Intelligent Fault Detection for Proton Exchange Membrane Fuel Cell PEMFC Based on Artificial Neural Network ANN

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Abstract

In this paper a fault detection and isolation (FDI) for proton exchange membrane fuel cell (PEMFC) has been presented. Artificial Neural Network (ANN) is used to detect the faults. An Input\output data set have been acquisitioned from PEMFC and used to design a neural network model. The model designed gives a steady state prediction for a given input. When the changes in output of the plant voltage or current due to any emergence events, the output of the PEMFC is compared to the output of the model, then a residual signal is monitored and used to detect the faults. Three types of faults have been studied in the presented work, these are; Abrupt, Incipient and Intermittent faults. The steady state model designed and simulated using Matlab. The validation performance of the designed model is 0.029. The model shows a very good ability to predict outputs and hence detect faults.

Keywords: PEMFC, Artificial Neural Network, Fault Detection and Isolation.

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1. Introduction

Detecting fault immediately is one of the most important factors in increasing the lifetime of the fuel cells. For the detection, diagnosis and correction intelligent and automated systems are so important lately [1].

The Proton Exchange Membrane Fuel Cell(PEMFC) is very popular because of its low temperature range and solid membrane that makes it easy start-up device compared with other generating sources [2].

Fuel cells convert chemical energy to electricity, heat and water [3]. There are many types of fuel cells but the PEMFCs are the best since they give great start-up and shutdown curves and they are compact, low weight and temperature [4].

ANNs are computational or mathematical models which are inspired from biological networks [5].Back Propagation Neural Network (BPNN) is a supervised algorithm, most popular and the feed forward ANN proposed by [6].

The model based fault detection and diagnosis (FDD) presented by T. Escobet [7]designed with computing residuals and comparing the parameters. While Ali.Mohammadi used 2D variation of pressure, temperature and humidity to design a FDD circuit [8]. Then Antoni Escobet presented The VisualBlock-FIR FDD system [9].

In this work BPNN architecture proposedand used to form a black box model that predicts the parameters of the system without knowing the equations of this system. This feature gives a great ability to represent nonlinear complex systems by Field programmable gate array (FPGA) which accepts only linear systems. The algorithm used to train the network is Levenberg- Marquardt algorithm. The program language used to simulate this study is Matlab\Simulink.

This paper is outlined as follows: in section 2, fuel cell fundamentals are recalled. Section 3 describes the fault detection and isolation (FDI) concept. Section 4 shows the simulation results with discussion. Section 5 contains the conclusion.

2. Fuel cell

Among all types of fuel cells the PEMFC have been selected to be studied and controlled due to its advantages over the other types. The PEMFC model in Matlab shown in figure (1) used in this work. The parameters of this model (6kw-45Vdc) are listed in table (1) according to the model proposed by [10] and [11] which has been first added in the version Matlab2014

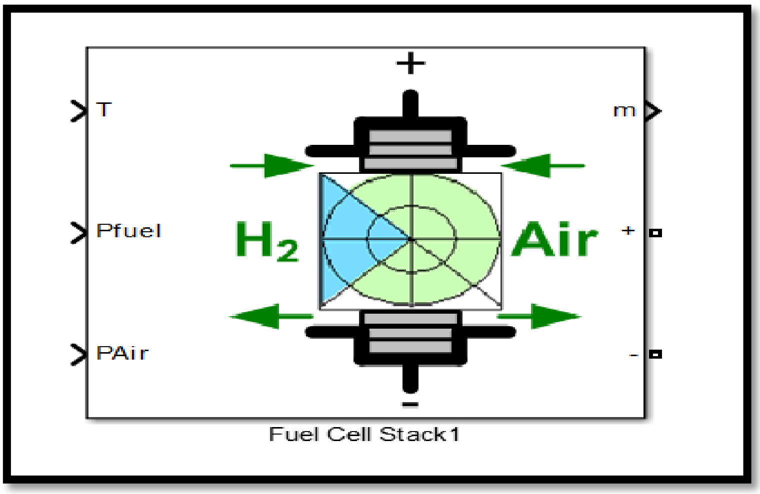

Figure 1: PEMFC Matlab\Simulink model

Table 1: PEMFC Matlab model parameters

Present Model	**6 kw 45Vdc**	
Voltage at 0A and 1A	65V	63V
Nominal operating point	133.3A	45V
Maximum operating point	225A	37V
Cells no.	65	
Efficiency of stack	55%	
Temperature of operation	65 Celsius	
Nominal supply Fuel pressure	1.5 bar	
Nominal supply Air pressure	1 bar	

The Input\Output data set acquisition is done by the connection shown in figure (2), more than hundred readings taken to form the data set

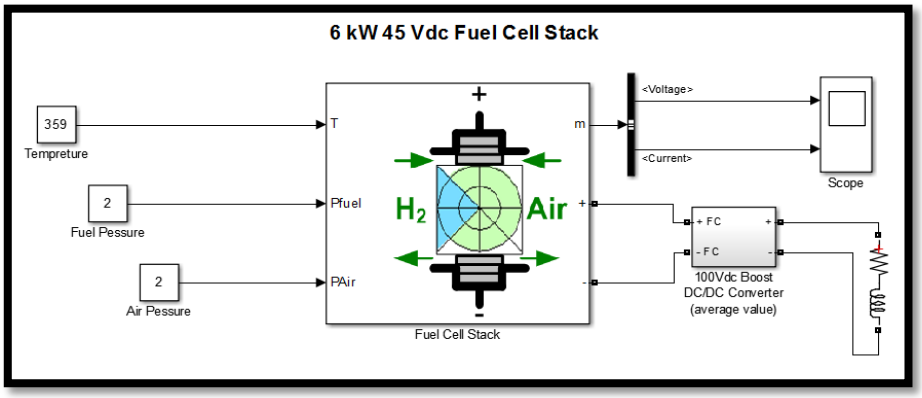

Figure 2: Data acquisition connection

3. Fault detection and isolation (FDI)

Productivity and performance of the system is effected majorly by faults. So FDI is required to handle these faults to minimize the maintenance and cost and hence optimize the operation of the system [12].

For FDD problem, the best way is the model based fault terminology where the outputs are compared and a residual signal is generated. The decision making is based on the threshold which can be changed and adjusted to adapt the required sensitivity and hence the cost of the system [1].

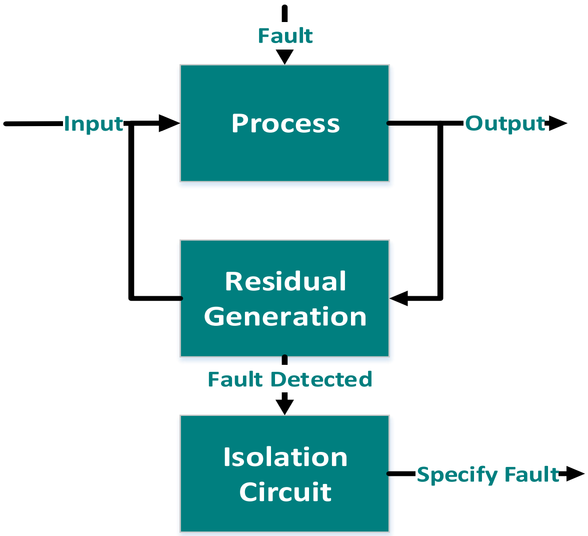

Figure 3: Model based FDI circuit

Three kinds of faults considered in this study: Abrupt, Incipient and Intermittent faults. Three input parameters (Temperature, fuel pressure and Air pressure) and two output parameters (Voltage and current).

The LMA is used in many software applications for solving generic curve-fitting problems. The algorithm was first published in 1944 by Kenneth Levenberg [13].

4. Simulation results and discussion

The best algorithm\activation function pair is: first hidden layer: 10, second hidden layer: 4, activation function: softmax, training algorithm: trainlm(Levenberg-Marquardt algorithm),that gives the smallest error for train, test and validation (0.029229) as shown in figure (4).

Softmax regression is a generalized form of logistic regression. The function is given by equation (1) [14]:

$$\sigma\{z\}_j = \frac{e^{zj}}{\sum_{k=1}^{M} e^{zk}} \quad \text{Where: } j = 1, \ldots, M. \qquad \ldots (1)$$

After the neural network model is designed it can be used to simulate all types of faults, first it is connected with the Matlab model for testing. Then the fault incarnation follows the acquisition.

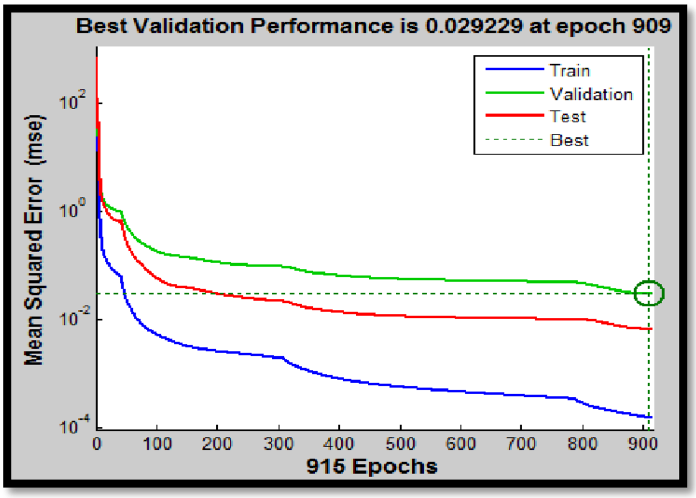

Figure 4: ANN training

4.1 Abrupt fault

This type of fault can be represented in simulation by Step signal that is added to the input signal of the PEMFC as seen in figure (5). The PEMFC output voltage is compared with the output voltage of the NN model and a residual signal is generated by subtraction see signal four that enters the scope in figure (6).

A step of amplitude (10), chose according to the temperature values range, is introduced at time (12second) to be sure that the transient change is finished, and the signals shown in figure (6).

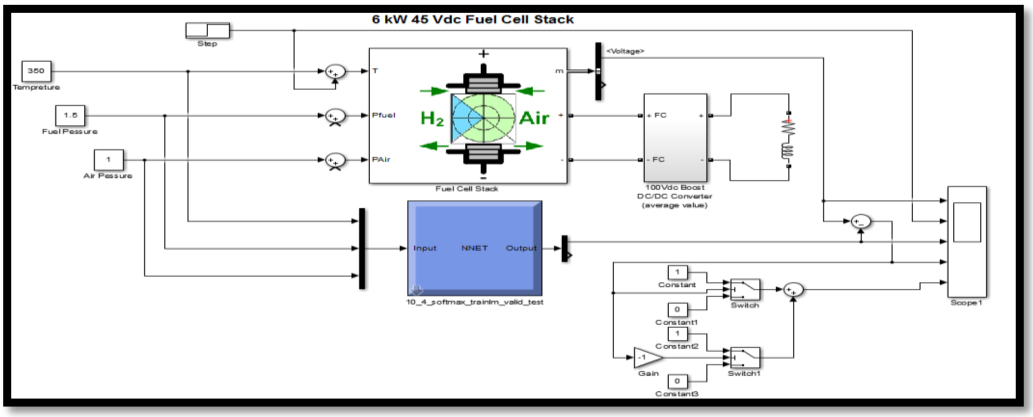

Figure 5: Abrupt fault addition graph

In figure (6) the threshold is 1, this value chose by try and fail to show how the fault is detected, so the digital signal (scope 5) becomes 1 when the residual becomes more than one which means there is a fault, and this signal is called Fault index.

Similar results appear by changing the step amplitude and the threshold. The fault can be inserted to the second and third input, similar results produced.

Abrupt fault examples in real practical PEMFC are:

- A sudden crack in one of the pipes or valves.
- A hit from an external object that changes the cell parameters.

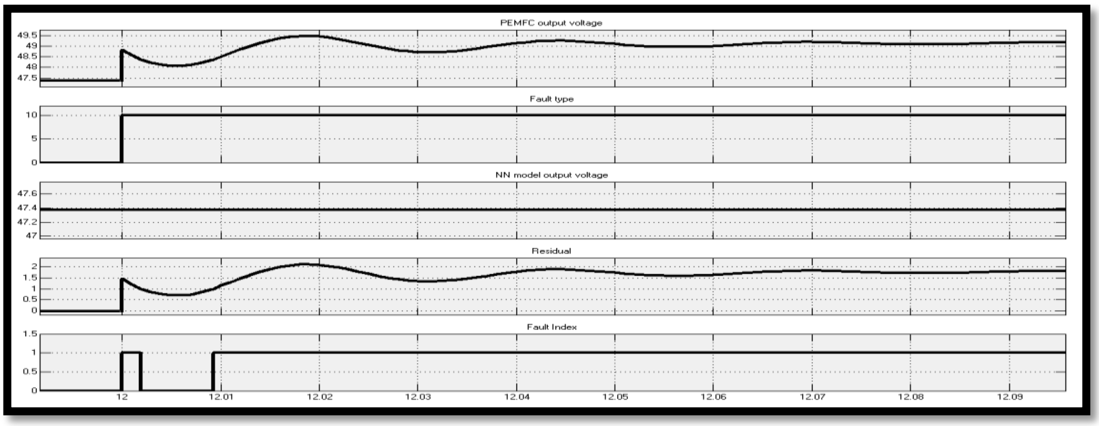

Figure 6: Abrupt fault addition signals*.*

4.2 Incipient fault

This type of fault can be represented in simulation by a ramp signal that is added to the input signal of the PEMFC as seen in figure (7). In this figure the fault is added to the fuel pressure input. The shape of the ramp and the other signals are shown in figure (8).

Incipient fault examples in real practical PEMFC are:

- A leak in one of the pipes or valves that makes the outputs decrease slowly.
- A failure in the cooling system that leads to an increase or decrease in the temperature.

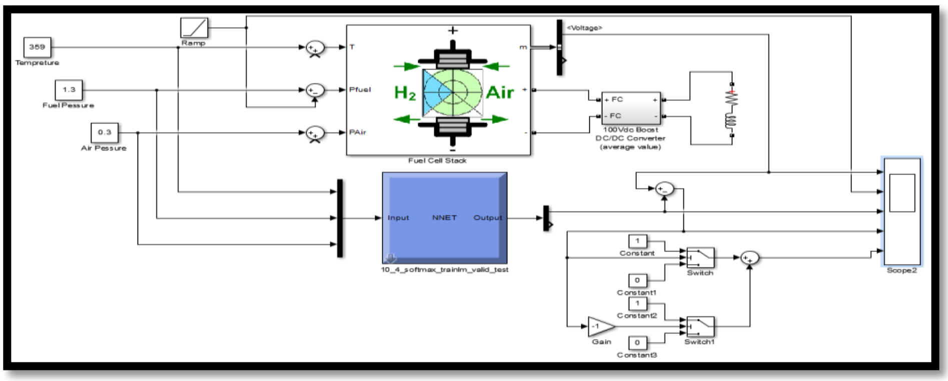

Figure 7: Incipient fault addition**.**

As seen in Figure (8), due to the ramp with slope of 4 and start time at 6 and the threshold is 0.5, the incipient decrease in the fuel pressure leads to gradual decrease in the output voltage. The system detected the decrease when the residual exceeded threshold value.

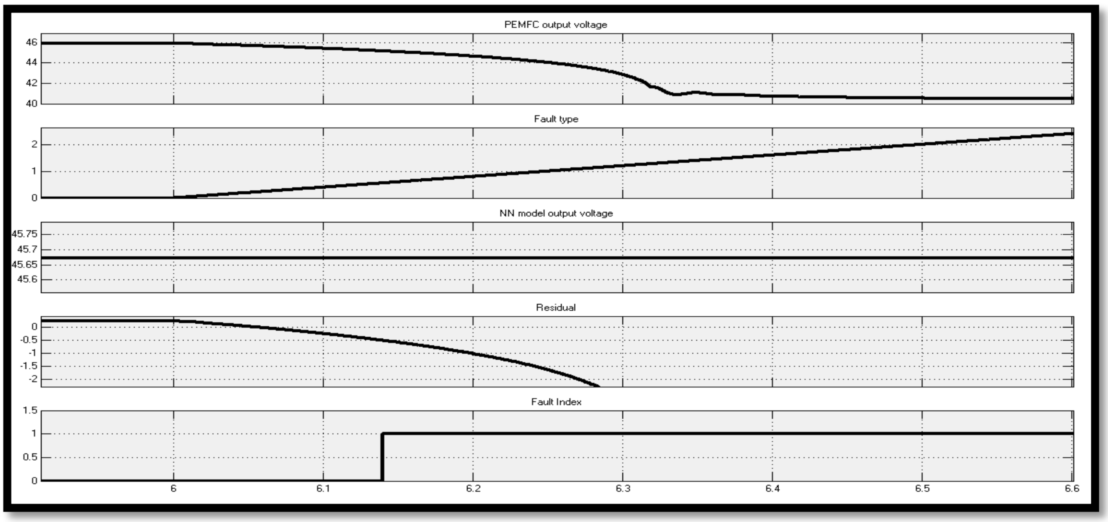

Figure 8: Incipient fault addition signals.

4.3 Intermittent fault

This type of fault can be represented in simulation by Random signal that is added to the input signal of the PEMFC as seen in figure (9). In this figure the fault is added to the Air pressure input. The shape of the random and the other signals are shown in figure (10).

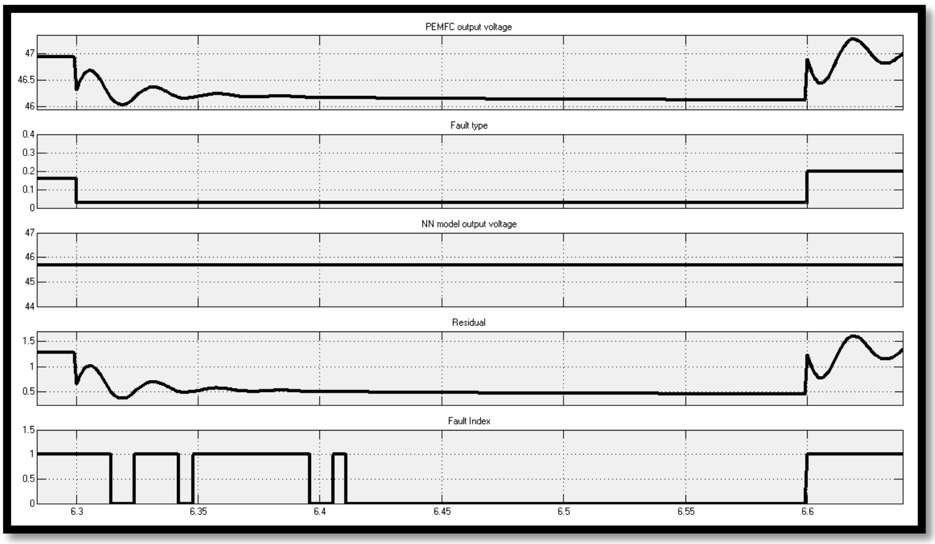

Figure 9: Intermittent fault addition

As seen in Figure (10) the Intermittent change in the fuel pressure, due to a random signal of 0.3 and sample time 0.3 with threshold of 0.5, leads to a change in the output voltage. The system detected the fault perfectly. Intermittent fault example in real practical PEMFC is a temporary change in the temperature or one of the parameters due to external or internal effect.

After detecting the fault it should be isolated, so an isolation circuit is designed to specify and identify the location of the fault.

The isolation circuit compares the inputs to the PEMFC, which is faulty, and the inputs of the NN model which is healthy. This circuit enabled by the fault index signal shown in scope 5 in the previous figures.

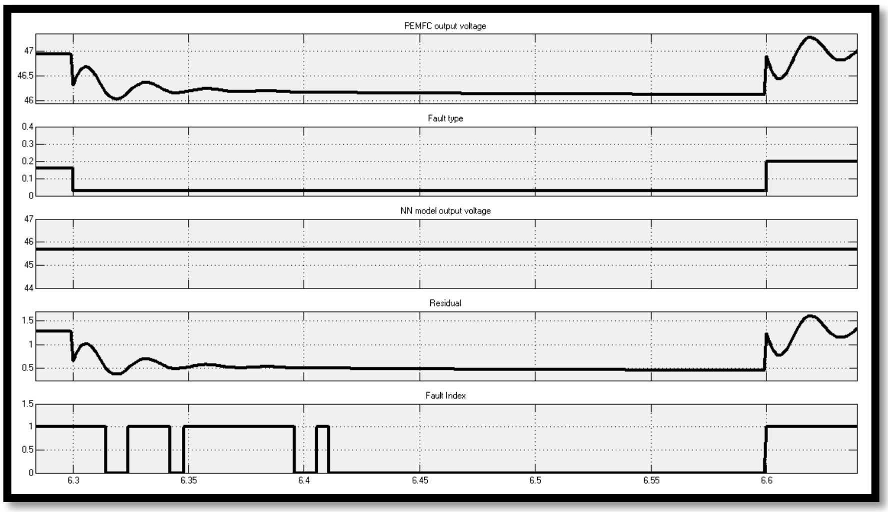

Figure 10: Intermittent fault addition signals.

The Isolation subsystem created is shown in figure (11) and its internal components are shown in figure (12).

The output of the Isolation circuit defines the faultaccording to Table (2).These codes are proposed in this work to be used in the diagnosis circuit which could be future work.

Table 2: The output of the Isolation circuit

Isolation output (F1F0) code	Description
11	Core temperature fault
10	Fuel pressure fault
01	Air pressure fault
00	Fault free

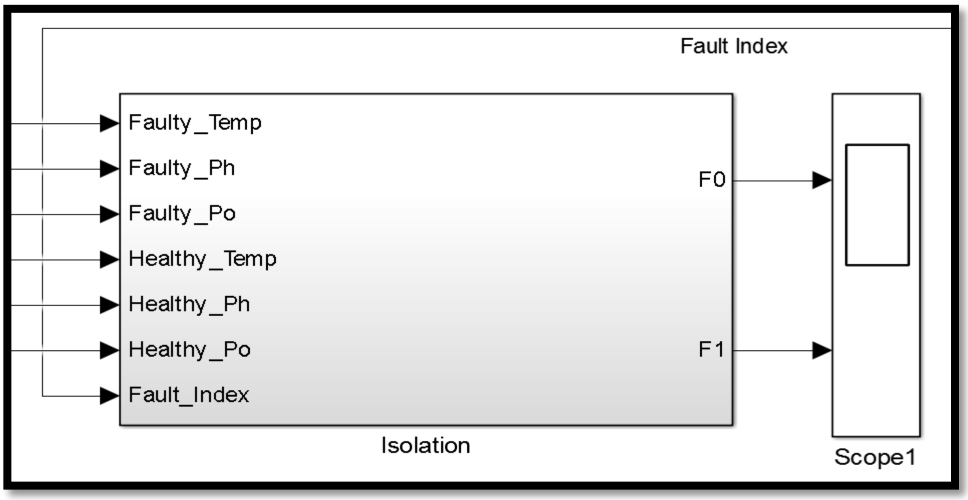

Figure 11: Isolation subsystem

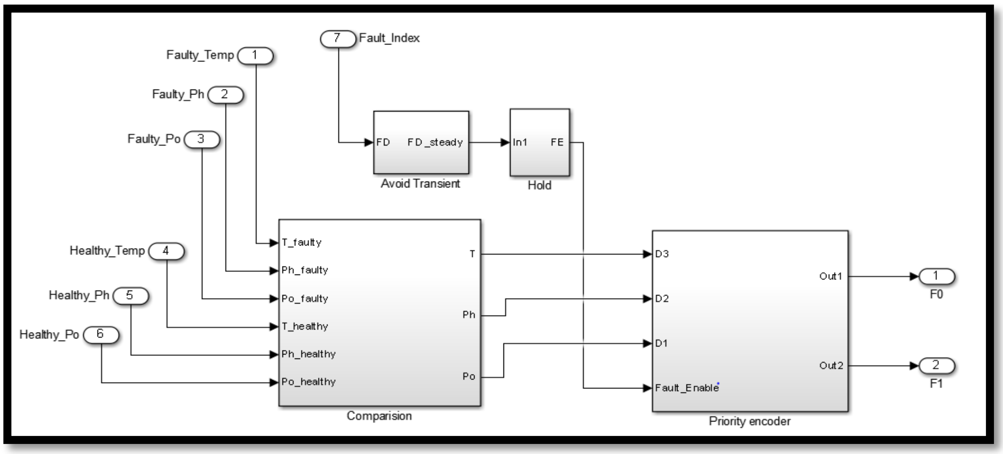

Figure 12: Internal structure of the Isolation subsystem

5. Conclusion

In this work a black box neural network model designed for a 6kw 45V PEMFC. This model is used to detect faults then the fault can be isolated by the isolation circuit designed. The model is used and designed only for steady state analysis (i.e. the transient or start up changes of the parameters are neglected). The proposed system gives good results to do the detection and the isolation. And it can be modified and adjusted for the level of sensitivity and cost required. The system can be downloaded to a hardware platform.The proposed system can be re-designed using other intelligent techniques. The system can be converted and compiled to be downloaded to a hardware platform like FPGA.A diagnosis circuit can be added to the system utilizing the code produced by the isolation circuit alsoadding a Graphical Unit Interface (GUI) to the system as a facility tomonitorall system parameters.

6. References

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منظومة ذكية لكشف الاعطال لخلية وقود هيدروجينية ذات غشاء التبادل البروتوني بالاستناد الى الشبكة العصبية الاصطناعية

م.د. عباس حسين عيسى* حسين محسن هادي*

المستخلص

في هذا البحث تم تقديم نظام كشف الاخطاء لخلية وقود هيدروجينية ذات غشاء التبادل البروتوني. تم استخدام احد خوارزميات الشبكات العصبية الاصطناعية لاكتشاف الاخطاء. باستحدام مجموعة بيانات قيم مداخل ومخارج خلية الوقود المعنية تم تصميم نموذج يعطي توقع لقيم المخارج. عند تغير قيمة المداخل يتم مقارنة مخارج خلية الوقود مع مخارج النموذج وبذلك يتم توليد اشارة المتبقي التي من خلالها يتم اكتشاف الاخطاء. تم تصميم نموذج القيم المستقرة باستخدام الماتلاب . اظهر الموديل نتائج جيدة جدا في الفحص والتدريب وبنسبة خطأ مقدارها 0.029 .

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