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A signal-based method for fast PEMFC diagnosis

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HIGHLIGHTS

- A novel signal-based approach is proposed for the PEMFC fault diagnosis.
- The state-of-health is estimated by using the wavelet transform approach.
- The results are coming from the analysis of the energy and the entropy of a signal.
- The robustness of the method is carried out by using a large database.
- Experimental data verify the efficiency of the method for an air supplying fault.

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ABSTRACT

This paper deals with a novel signal-based method for fault diagnosis of a proton exchange membrane fuel cell (PEMFC). Thanks to an in-lab test bench used for the experimental tests, various parameters can be recorded as electrical or fluidic measurements. The chosen input signal for the diagnosis uses no additional expensive and no intrusive sensors specifically dedicated for the diagnosis task. It uses insofar only the already existing sensors on the system. This paper focuses on the detection and identification of a high air stoichiometry (HAS) fault. The wavelet transform (WT) and more precisely the energy contained in each detail of the wavelet decomposition is used to diagnose quickly an oversupply of air to the fuel cell system. Finally, some experimental results are presented according to different input signals, in order to prove the efficiency of the patented method.

1. Introduction

The main challenges for the fuel cell system are to reduce its cost, to improve its reliability and to extend its lifetime. The department of energy (DoE) sets some objectives to be met by the end of 2015, both for automotive and stationary applications [1]. These objectives mainly concern the cost and the lifetime. The cost of fuel cell power systems must be reduced before they can be competitive with gasoline internal combustion engines (ICEs). In fact, conventional automotive ICE power plants currently cost about US$25–US$35/kW (August 2011); thus, a fuel cell system needs to cost less than US$30/kW [2,3] to be competitive. A significant fraction of the cost of a PEM fuel cell comes from precious-metal catalysts that are currently used on the anode and cathode for the electrochemical reactions. In addition, fuel cell power systems will be required to be as durable and reliable as current automotive engines (i.e., 5000 h lifespan [150,000 miles equivalent] with less than 10% loss of performance by the end of life) and able to function over the full range of external environmental conditions (−40°C to +40°C) [4]. The current fuel cell lifetime remains still too low (about 2500 h for a PEMFC under actual automotive constraints, which is the main technology used for cars) [5]. Some technical and technological solutions to improve the performances of fuel cells exist. Diagnosis methods can also be associated to prevent abnormal or non-optimal operating conditions for the fuel cell system, in order to improve the fuel cell reliability. A review resumes the main factors affecting the lifetime of PEMFC in vehicle applications [6]. The authors analyze the reasons of the degradation of fuel cell and present some mitigation measures during the fuel cell operation. Based on the lifetime problem, diagnosis researches and approaches aim to find solutions to improve the fuel cell lifespan. Various kinds of fault diagnosis exist and can be classified in two main approaches: the model-based

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approaches [7] and the non model-based [8] approaches. The first ones takes into account the physical behavior of the fuel cell system in order to build a valid model of the fuel cell. This model is performed to generate residuals that are used for the diagnosis task. In [9] an in [10], the authors present stack models to analyze parametric study of the stack only. In [9] a one-dimensional model is developed. In [11], it is a zero-dimensional and steady-state PEMFC model which is proposed. The development comprises various types of heat exchangers, compressors, pumps, separators. The aim is to study the thermal and water management of a PEMFC in fork-lift-truck power system. Thus, a semi-empirical solution is used to reproduce the experimental polarization curves of the fuel cell. In [12], a quantitative model-based fault detection and diagnosis approach for building applications that employs a state observer and dynamic model-based is proposed. This approach is developed in order to detect and diagnose some faults which occur on heating, ventilation and air conditioning systems. In [13] a fuel cell stack model is realized thanks to Aspects Dynamics™ simulation tool to study the effect of nitrogen crossover on purging strategy in PEM fuel cell systems. In [14], a model of a 5-kW PEM fuel cell system is developped based on previous works [15]. The model is composed of four elements: a compressor that supplies air, the fuel cell stack, a pressure control valve that drives the pressure inside the cathode chamber and a humidifier. The authors focus on the air group control problem. The entire fuel cell system is modeled in details in order to observe the evolution of internal state variables during a power delivery operation. The non-model based approaches do not require any knowledge of the whole internal behavior of this multiphysics system. The principle is based on signals or datas acquired during experimental tests which are used to teach the diagnosis algorithm in order to recognize, later, the same state of health (SoH) as learned. The methodology presented in this paper belongs to the second category: it is a signal-based approach that uses a mathematical transformation called wavelet transform (WT). The Fourier transform [16] is used to reveal the frequency content of a signal $s(t)$ but it does not allow to localize in time some events such as pulses, jumps and frequency variations which can appear in the signal [17,18]. The WT belongs to the multi-resolution analysis methods class. This approach allows showing some local features under different scales and time localizations of a signal [19]. The WT is used in different contexts of research as wind speed prediction [20,21] or for price forecasting [22], also for the fault diagnosis for temperature, flow rate and pressure sensors in variable air volume systems and for the energy management of an fuel cell hybrid vehicles [23]. In this paper, the aim is to generalize a signal-based fault diagnosis method to several types of fuel cells. Previously, a method is patented on a SOFC system which operate in different operating conditions. By analyzing the energy and the entropy behaviors, the state of health of the SOFC is determined. Based on this efficient results and on the good performance of the signal-based approach for fault diagnosis, the methodology is transposed to the PEMFC system. A specific fault is studied in this paper: a high air stoichiometry fault. The stoichiometry is an important parameter on a PEMFC system. So, the aim is to diagnose the fuel cell SoH as fast as possible by reproducing the same approach tested in the patent [24] on the SOFC system. In this way, the same specifications are used and tested on a PEMFC system. Experimental tests are performed on a 40-cell stack, in different stoichiometry ratios, in order to obtain a large database available for the signal-based method. Like in the patent [24], the estimation of the SoH is based on voltage signals coming from sensors available on the fuel cell test bench. It can be notice that the signal-based approach is well adapted to the fuel cell voltage signals [25]. This paper is organized as follows: firstly, the test bench and the fuel cell used to achieve experimental testing are presented. The protocols for testing the normal and the abnormal operating conditions will be described in the Section 2.2. Thereafter, the novel and patented signal-based fault diagnosis method based on WT is explained. The wavelet decomposition steps and the focus on the energy contained in the inlet signal are presented in the following section. Finally, some diagnosis results based on three different input signals are given in Section 4.

2. Experimental setup

2.1. Experimental equipments

The experimental tests are performed on an electrochemical 40-cell stack assembly (Fig. 1). The experiments have been completed in the frame of a national French ANR project called DIAPASON 2 [26], which focuses on the diagnosis of PEMFC by using non-intrusive methods. The final aim of this project ended in 2013 was to realize an embedded system capable of diagnosing fuel cell system on-line. Algorithms were implemented in order to make real-time diagnosis by taking into account an abnormal increase of the fuel cell temperature, an electrical power converter short circuit problem, a low air supply and so on [27–29]. Some specifications about the considered PEMFC stack are given in Table 1.

The 40-cell stack is tested on a test bench which is designed for testing up to 10 kW PEM fuel cell stacks. The considered test bench is presented on Fig. 2. Various measurements can be obtained in order to detect a deviation from the nominal operating conditions. Over time, a list of standard parameters measured was defined. It includes electrical basic measurements (stack and cell voltages, load current and electrical power) and fluidic parameters as pressure, mass flow, humidity and temperature.

From left to right on Fig. 2, there are the air and the hydrogen supplies with mass flow controllers. Then, two bubblers are available to humidify the inlet gases. The humidity can be adjusted by changing the bubbling type humidifier temperature. The temperature is maintained thanks to heating pipes rolled up around gas inlets. A cooling circuit is designed to refresh the fuel cell in order to control the stack temperature at a given value. When a heating problem appears, some iced-water is injected into the primary deionised water circuit through an exchange device. For each gas input and output, the pressure, the humidity and the temperature sensors provide full operating conditions. The stack voltage, the cell voltages and the load current are recorded too. All acquired

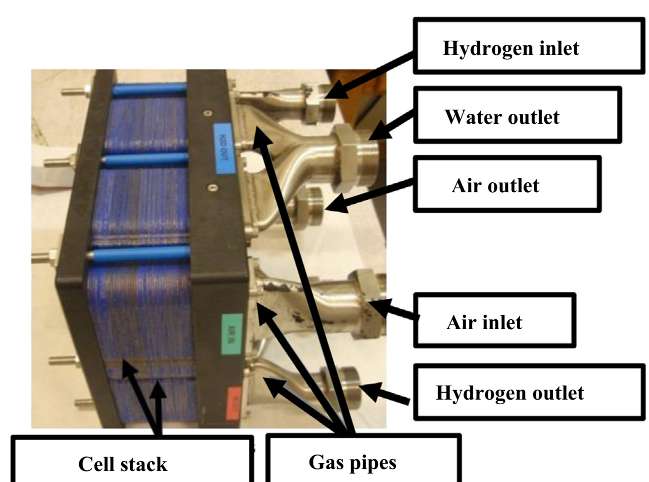

Fig. 1. 40-cell stack with specified inputs and outputs.