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Short Communication

On the issue of the PEMFC operating fault identification: Generic analysis tool based on voltage pointwise singularity strengths

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ABSTRACT

The purpose of this article is to study the portability of a non-intrusive and free of any external/internal disturbance diagnosis tool devoted to the monitoring of the State of Health (SoH) of PEM Fuel Cell (PEMFC) stack. The tool is based on a thorough analysis of the stack voltage signal using a multifractal formalism and wavelet leaders. It offers well-suited signatures indicators on the SoH of the Fuel Cell. Some relevant descriptors extracted from these patterns (singularity features) are used in the frame of Machine Learning approaches to allow the PEMFC fault identification. The proposed diagnosis strategy is evaluated with two different PEMFC stacks. The first one is designed for automotive applications and the second one is dedicated to stationary use (micro combined heat and power - μCHP application). The classification results obtained for the both stacks indicate that the proposed PEMFC diagnosis tool allows identifying simple operating faults as well as more complicated operating situations combining several fault types.

Introduction

Fuel cells (FC) are considered as a promising alternative way for energy conversion [1]. To ensure their durability, reliability and safety, many fault diagnosis and fault tolerant control methods have been proposed. These methods can be classified into two groups: model-based methods [2–5] and data-driven methods [6–8]. The methods of the first group are very cumbersome and complex because they require an in-depth knowledge of the multi-physical mechanisms (thermal, electrical, electrochemical, and fluidic ones) which can

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occur in FC systems. They are based on numerous parameters governing its operation, and their values are difficult to estimate. Some model-based methods allows a deeper understanding of the FC physics but they might be not suitable to provide an accurate/quantitative description of the FC performances. Hence, the data-driven techniques attract more and more attention because of their simplicity regarding the implementation and the good performances obtained without profound system structure knowledge. They are supported by efficient signal processing methods as: Fourier transform [9], multi-resolution analysis [10,11], singularity analysis [12,13]. For fault identification and isolation tasks, some works use Electrochemical Impedance Spectra (EIS) as normal or faulty operation signatures to supply artificial intelligence algorithms (based for instance on fuzzy logic [14] or neural networks [15]) or conventional pattern recognition approaches (based on Support Vector Machines (SVM) [16], K-Nearest Neighbors (KNN) [13] methods).

This work aims at studying the portability of an innovative data driven approach dedicated to PEMFC diagnosis, named singularity analysis. This method consists in analyzing the pointwise singularities stamped in the stack voltage signal for various FC operating conditions. The singularity features are then summarized in the form of concave arcs estimated thanks to a set of mathematical equations, baptized multifractal formalism [17–19]. The advanced analysis tool, named Voltage Singularity Spectrum (VSS) is then obtained using a non-intrusive manner and without affecting in any way the FC operation. Indeed, no external additional AC-solicitation has to be superimposed to the existing DC load current as it is the case in the usual EIS operation mode.

This paper is organized as follow. Section 2 deals with the experimental work and environment conducted with two PEMFC stacks. In section 3, a brief mathematical foundation of the singularity measurement is given. In section 4, we show how it is possible to make the singularity spectrum combined with Machine Learning techniques as a PEMFC diagnosis tool. Then, the portability of the proposed tool is discussed. Main conclusions are given in Section 5.

Experimental

Synopsis of the investigated PEM fuel cells

In our study, two PEMFC stacks are experimented to evaluate the portability of the proposed diagnosis tool. The first one is an 8 cell stack designed for automotive applications and manufactured by CEA (Alternative Energies and Atomic Energy Commission). The second one is a 12 cell stack dedicated to stationary application (micro Combined Heat and Power – μCHP application). It is designed and marketed by Riesaer Brennstoffzellentechnik GmbH and Inhouse Engineering GmbH, Germany.

The first stack ($PEMFC_{Auto}$) is made of metallic gas distributor plates. The electrode active surface of a cell is equal to 220 cm^2. It is fed by air at cathode and pure hydrogen (H_2) at anode. A summary of the FC nominal operating conditions is given in Table 1. The stack operates with a nominal current of 110 A. A picture of the stack is shown in Fig. 1(a).

Table 1 – $PEMFC_{Auto}$ nominal operating conditions.

Coolant flow: deionized water	2 l/min
Anode stoichiometry rate (H_2)	1.5
Cathode stoichiometry rate (air)	2
Absolute pressure for H_2 and air inlets	150 kPa
Max. anode – cathode pressure gap	30 kPa
Temperature of the cooling circuit	80 °C
Anode and cathode relative humidity rate	50%
Nominal Current	110 A

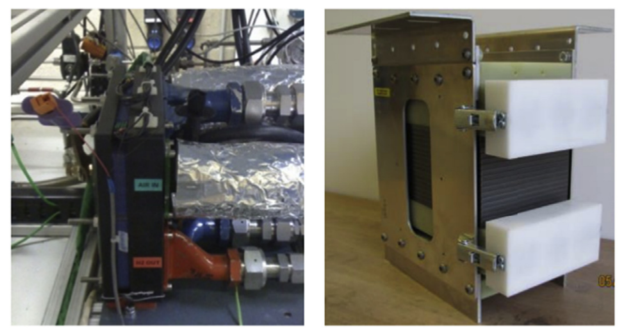

Fig. 1 – Pictures of the two investigated PEMFC stacks: a) 8 cell stack designed for automotives ($PEMFC_{Auto}$), b) 12 cell stack designed for μCHP operation ($PEMFC_{\mu CHP}$).

The second stack ($PEMFC_{\mu CHP}$) is fed by air at cathode, and at anode by a fuel mixture (75% of H_2 and 25% of carbone dioxide – CO_2) simulating a reformat. It is made of graphite gas distributor plates. The active surface of the electrode is 196 cm^2. The stack operates with a nominal current of 80 A. A picture of the stack is given in Fig. 1(b). A summary of the FC nominal operating parameters and other main characteristics are given in Table 2.

Experimental process

The above described PEMFCs were experimented with test-benches developed in the FC platform of Belfort, France. It includes mainly:

- A complete gas conditioning sub-system with gas humidifiers at anode and cathode,
- A test stand section dedicated to the control of the temperature inside the stack and including the FC primary water circuit,
- An electric/electronic management sub-system,
- An electronic load.

Table 2 – $PEMFC_{\mu CHP}$ nominal operating conditions.

Coolant flow: deionized water	3 l/min
Anode stoichiometry rate (H_2 and CO_2 mix)	1.3
Cathode stoichiometry rate (air)	2
Absolute pressure for H_2 and air inlets	150 kPa
Max. anode - cathode pressure gap	20 kPa
Temperature of the cooling circuit	75 °C
Anode and cathode relative humidity rate	50%
Nominal Current	80 A

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