INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 35 (2010) 8022–8029

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Estimation of fuel cell operating time for predictive maintenance strategies

R. Onanena [a,b,c], L. Oukhellou [c,d], D. Candusso [a,c,*], A. Same [c], D. Hissel [a,b], P. Aknin [c]

[a] FC LAB, Techn'Hom, rue Thierry Mieg, 90010 Belfort Cedex, France
[b] FEMTO-ST (UMR CNRS 6174), ENISYS department, University of Franche-Comté, France
[c] INRETS - LTN, "Le Descartes 2", 2 rue de la butte verte, 93166 Noisy-le-Grand Cedex, France
[d] CERTES Université Paris 12, 61 avenue du Gal. de Gaulle, 94100 Créteil, France

ARTICLE INFO

Article history:
Received 18 January 2010
Received in revised form
19 March 2010
Accepted 8 May 2010
Available online 12 June 2010

Keywords:
Fuel cell
Durability
Reliability
Diagnostic
Predictive maintenance

ABSTRACT

Durability is one of the limiting factors for spreading and commercialization of fuel cell technology. That is why research to extend fuel cell durability is being conducted world wide. A pattern-recognition approach aiming to estimate fuel cell operating time based on electrochemical impedance spectroscopy measurements is presented here. It is based on extracting the features from the impedance spectra. For that purpose, two approaches have been investigated. In the first one, particular points of the spectrum are empirically extracted as features. In the second approach, a parametric modeling is performed to extract features from both the real and the imaginary parts of the impedance spectrum. In particular, a latent regression model is used to automatically split the spectrum into several segments that are approximated by polynomials. The number of segments is adjusted taking into account the *a priori* knowledge about the physical behavior of the fuel cell components. Then, a linear regression model using different subsets of extracted features is employed for an estimate of the fuel cell operating time. The effectiveness of the proposed approach is evaluated on an experimental dataset. Allowing the estimation of the fuel cell operating time, and consequently its remaining duration life, these results could lead to interesting perspectives for predictive fuel cells maintenance policy.

1. Introduction

Fuel Cells (FCs) appear to be a promising and environmentally friendly energy conversion technology for the future, especially for transport applications. However, the economical viability of FC systems, especially in the transportation sector, depends notably on improving the stack durability and reliability. Indeed, the stack is prone to material degradation (e.g. poisoning of the catalyst sites, loss of proton conductivity in the membrane, corrosion of plates, etc.) and the performance decay induced is strongly linked to the operating conditions (i.e. pollutants in the reactants, insufficient amounts of reactive gas flows versus the load current demand, operating temperature, mechanical constraints on the membrane electrode assemblies, etc.) [1–5]. Typical life requirements range from at least 5000 h for car applications to 20 000 operating hours for bus applications. Moreover, when dealing with durability and reliability, the efficient diagnosis of FC stack and system appears as a major issue. The development of diagnostic schemes can help evaluating the FC state-of-health, and thus speed up the development cycle and deployment of new FC vehicles.

* *Corresponding author*. INRETS - LTN, "Le Descartes 2", 2 rue de la butte verte, 93166 Noisy-le-Grand Cedex, France. Tel.: +33 3 84 58 36 33; fax: +33 3 84 58 36 36.
E-mail address: denis.candusso@inrets.fr (D. Candusso).

0360-3199/$ – see front matter © 2010 Professor T. Nejat Veziroglu. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijhydene.2010.05.039

Various diagnosis approaches for FC stacks and systems have been developed. They include model-based methods [6–10], gray or black box model approaches using fuzzy logic [11], design of experiment methods [12], neural networks [13], or non-parametric identification by Markov parameters [14]. Recent FC stack diagnosis approaches based on fuzzy clustering [15] and Bayesian networks have been proposed [16].

This paper presents a pattern-recognition-based diagnosis aiming to estimate the FC operating time from Electrochemical Impedance Spectroscopy (EIS) measurements done at approximately regular time intervals throughout two different Proton Exchange Membrane (PEM) FC durability tests (conducted on two stacks, noted here as FC1 and FC2). Our analysis uses data collected on FC1 and FC2 to ensure the robustness of the obtained results. Furthermore, with the proposed approach, we are also able to estimate the remaining FC lifetime. For predictive maintenance purposes, it is obviously important to know how FC performances evolve throughout its working.

The complete diagnosis system consists of several steps, shown in Fig. 1. From each recorded impedance spectrum (high dimensional data), a feature extraction is performed to generate the features (low dimensional data). The goal of extraction and selection is to find a small number of features among the original ones that are particularly informative for the problem to be solved. Furthermore, dimensionality reduction is also essential when the available training dataset is small as it is in our case, otherwise the well known phenomenon of curse of dimensionality could inevitably appear, leading to over-fitting [17,18]. Finally, linear regression between a meaningful subset of features and the considered output (operating time) is achieved.

The paper is organized as follows. Section 2 describes the two ageing tests and highlights the link between FC ageing and EIS measurements. Section 3 focuses on the two different feature extraction methods that have been used. Section 4 presents the different solutions for operating time estimation based on linear regression and compares the different results obtained with the two feature extraction approaches. Experimental results are reported in this section. Section 5 concludes the paper with some perspectives.

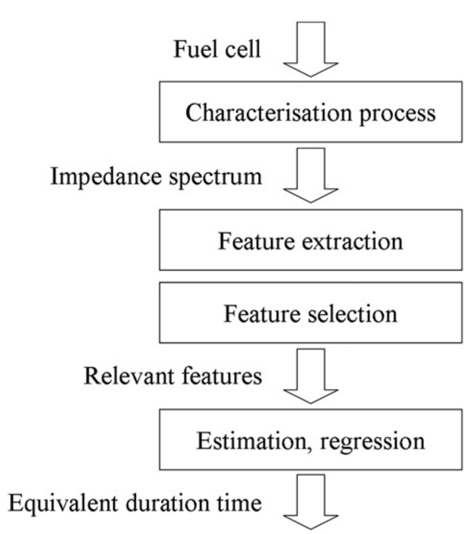

Fig. 1 – FC operating time estimation on the basis of a pattern-recognition-based approach.

2. Durability issues

2.1. *Ageing experiments*

In order to evaluate the influence of different factors on the ageing of FCs, experiments were carried out in FC LAB. The durability tests were performed on two identical small power PEMFC three-cell stacks of about 100 W during 1000 h. The testing conditions varied from one stack to another. The first stack (FC1) was operated in nominal and stationary conditions. The load current was constant and equal to 50 A. In the second test, the fuel cell (FC2), was operated under dynamical load current based on a real transportation mission profile (maximum current of 70 A was reached for an average of 12.5 A). Details on the test conditions and kind of current solicitation can be found in [19,20]. During these ageing tests, the stacks were characterized regularly (twice per week). To determine the number of characterization sequences, a trade-off was found between two different needs: on the one hand, a sufficient amount of collected data for the monitoring of the FC state-of-health, and on the other hand, the minimization of the perturbations due to the characterization sequences in the achievement of the durability tests. Except for the two first EIS spectra recorded on FC1 (at the beginning of the ageing test) and for the three first spectra measured on FC2 (at the beginning of the durability test), the characterizations were made at average time intervals of 63 h for FC1 and 75 h for FC2. These regular characterizations consist of recording polarization curves and impedance spectra. They have resulted in the constitution of a database made of 17 and 12 impedance spectra for FC1 and FC2 respectively. Note that the complete characterization test results are reported in [19,20]. In this paper, the ageing process is analyzed with the information extracted from impedance spectra only.

2.2. *Electrochemical impedance spectrum*

Since the polarization curve gives information about the static behavior of the FC, Electrochemical Impedance Spectroscopy (EIS) is used in order to obtain relevant information about its dynamical behavior. Considering this technique, the FC is operated at its standard (static) operating point and then additional small amplitude signals are applied. Each recorded impedance spectrum is a series of impedance measurements at discrete frequency points. EIS can be performed in two modes: potentiostatic (voltage control mode) and, like in our case, galvanostatic (current control mode). EIS allows the characterization of dynamic processes occurring at different timescales in the system. EIS has been widely employed by FC experimenters to study various phenomena, such as diffusion phenomena at cathode side, the ionic conductivity of membranes, pollutant effects and catalyst loading [7,9,21]. EIS can also be used to show the influence of the occurrence of a fault or the evolution of the dynamic behavior during an ageing process.