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Proton exchange membrane fuel cell behavioral model suitable for prognostics

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ABSTRACT

Prognostics and Health Management (PHM) is a discipline that enables the estimation of the Remaining Useful Life (RUL) of a system and is not yet much applied to Proton Exchange Membrane Fuel Cell PEMFC. However it could permit the definition of adequate conditions allowing extending PEMFC's too short life duration. For that purpose, a model that can reproduce the behavior of a PEMFC is needed. This paper presents a model of a PEMFC that could serve for a prognostics purpose. The model is composed of a static part and a dynamic parts that are independent. On one side, the static part is developed thanks to equations describing the physical phenomena and is based on the Butler–Volmer law. On the other side, the dynamic part is an electrical equivalency of physical phenomenon. The models are validated thanks to experimental data gathered in long term tests. For that purpose the parameters are successively updated based on characterization measurements (polarisation curves and EIS (electrochemical impedance spectroscopy)). Then the results of the model are compared to the ageing data in order to evaluate if the model is able to reproduce the behavior of the fuel cell. The usefulness of this model for prognostics is finally discussed.

Introduction

PEMFC is a promising alternative to the actual production of energy but has got technical bolts as the distribution and the storage of dihydrogen as well as a too short life duration [1]. In order to postpone the end of life, the development of Prognostics and Health Management (PHM) seems to be an adapted solution. The part of PHM that is highlighted here and that has not been investigated much in literature is Prognostics. The idea is to estimate the Remaining Useful Life of a system. For that purpose, as a starting point, a behavioral model, including ageing, of a PEMFC is needed. For modeling the behavior, different kinds of approaches can be highlighted, like data-based [2] or model-based [3], both largely present in the literature. However, neither of these models seems to fit the diagnostics purpose. Indeed, for examples, the ageing phenomena can hardly be added if only the micro

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Nomenclature

η_a	Voltage drop at the anode, V
η_c	Voltage drop at the cathode, V
τ_{Oc}	Time constante of the diffusion convection impedance, s
b_a	Tafel anode parameter, V^{-1}
b_c	Tafel cathode parameter, V^{-1}
b_{Oc}	Parameter of the variation law of R_{Oc}, V^{-1}
C_{dca}	Double layer capacity at the anode, F/cm^2
C_{dcc}	Double layer capacity at the cathode, F/cm^2
E_n	Nernst Potential, V
i	Number of EIS realized at each characterizations
j_{0a}	Exchange current density at the anode, A/cm^2
j_{0c}	Exchange current density at the cathode, A/cm^2
j_{0Oc}	Parameter of the variation law of R_{Oc}, A/cm^2
J_{AC}	Dynamic current density, A/cm^2
J_{DC}	Static current density, A/cm^2
J_{EIS}	Vector of the current densities for the EIS, A/cm^2
J_{pola}	Vector of the current densities for the polarization curve, A/cm^2
j_{Lc}	Limit current density at the cathode, A/cm^2
k	Number of characterizations
k_{Oc}	Parameter of the variation law of τ_{Oc}, $A\ s/cm^2$
L	Connectors' inductance, $H\ cm^2$
R_m	Membrane resistance, $\Omega\ cm^2$
r	Internal resistance (Static and Global model), $\Omega\ cm^2$
R_{Oc}	Module of the diffusion convection impedance, $\Omega\ cm^2$
R_{ta}	Transfert resistance at the anode, $\Omega\ cm^2$
R_{tc}	Transfert resistance at the cathode, $\Omega\ cm^2$
U	Stack Voltage, V
U_{AC}	Dynamic stack Voltage normalised per cell, V
U_{DC}	Static stack Voltage normalised per cell, V
U_n	Stack voltage normalized per cell, V
W_{Oc}	Diffusion convection impedance, $\Omega\ cm^2$

phenomenon happening in the fuel cell are modeled [4]. For that purpose, a model-based approach is developed in this paper in order to have a good precision and even to model some important internal parameters of the fuel cell. A combination of a static and a dynamic model is proposed and fulfills the need of a model in an efficient way. Indeed, added to the positive aspects of a model-based approach, this model is rather easy to implement, has a high enough accuracy with the description of internal parameters, and the ageing can be easily included.

This paper is structured as follows. First a presentation of the path made toward a behavioral model usable for prognostics is drawn, then the model developed is presented. Next the updating procedure, i.e. the tuning of parameters' values is explained for finally studying the validation thanks to the comparison between the simulated behavior and experimental results.

Backgrounds

Prognostics and health managment (PHM)

Every machine or system is deteriorating with time until reaching a faulty state. It can happen at an unsuitable time and trigger negative consequences as it prevents the system to ensure its mission. The maintenance could take a lot of time, and meanwhile, all the dependent systems are not able to carry on. Some loss of money or time and even security troubles can be triggered by this situation. PHM appears to be a solution to face this kind of problems [5]. Among the aims of PHM, the principals are:

- To improve the decision making process in order to increase the life duration of the system;
- To improve the availability and reduce the operational cost;
- To improve the security of the system.

PHM is described as composed of seven modules (Fig. 1) that allow defining the different steps followed in the process [6]. With a first part of observation composed by the data acquisition (module 1) obtained thanks to the sensors and by the data processing (module 2) which allows extracting some features. Then the analysis part is composed by modules 3, 4 and 5. Module 3 (condition assessment) aims defining the state of health of the system by detecting faults. Then, the module 4, diagnostic, assesses the origins of the faults. Module 5, prognostics, predicts the future state of health of the monitored system thanks to previous modules. It allows estimating the remaining useful life (RUL). The action part of PHM is composed by the last two modules. First, the decision support provides recommendations about the actions that

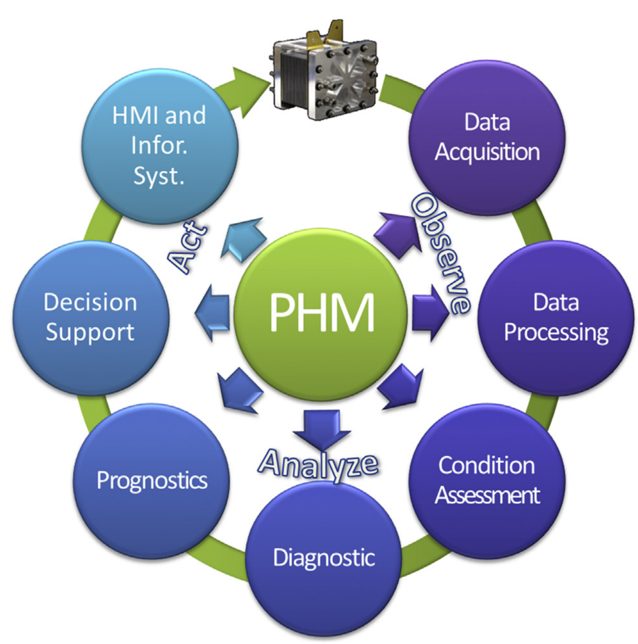

Fig. 1 – PHM modules adapted from Ref. [7].