

Model Ageing Fuel cell System

Supervision

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Topic

Sciences . PhD in electrical engineering.

Key words

Fuel Cell System, fault, ageing model, prognostics, decision, multi-stack system.

Context

A wide deployment of the fuel cell systems (FCS) cannot be achieved unless these systems are competitive with conventional solutions in terms of performance, cost and lifetime. As a matter of fact, the FCS must offer good performance and reliability at acceptable cost. Therefore, it is necessary to develop robust systems that are tolerant to faults with a minimal ageing rate.

It is therefore necessary to apprehend and master the operation, degradation and ageing of these systems, in order to anticipate faults and failures. Setting up reliable health indicators is a key point.

Pronostics and Health Management (PHM) allows to monitor and predict the future behavior of a system and its Residual Useful Lifetime RUL in order to take appropriate decisions on control to counteract the faulty operation states.

Within the SHARPAC team (part of the Energie department of FEMTO), numerous research works have been conducted on Prognostics of Fuel Cells, making the team one of the leaders on that topic at the international level [1, 2, 3, 4, 5]. However very few works on prognostics take into account the effect of degraded and aged components of the BoP. In fact, apprehending the ageing of the whole FCS could be very challenging, because the multi-physics, multi-scale characteristics of these systems brings up strong interactions and coupling between the components and parameters.

Scientific Objectives

The main objectives of this PhD thesis are to develop an ageing model of the Fuel Cell System and to estimate its Residual Useful lifetime (RUL). Finally, based on the output, ways to extend this RUL will be explored:

- **Experimentation:** long-term testing of the different components of a FC system will be conducted in order to collect a rich database that will feed the prognostics models. The testing campaigns will focus on BoP elements such as motor-compressor, cooling system pump, humidification system.
- **Modelling and ageing/damage function** of the different components. Combing experimental data and knowledge based physics will allow to develop hybrid robust ageing models of each sub-system of the BoP.
- **Modelling and ageing/damage function of the Fuel cell stack and interaction of the individual components** ageing. FC system are difficult to apprehend: the non-linear aspects of the involved phenomena, the reversible/irreversible characteristics of the faults and the strong interactions between parameters make the ageing modeling challenging [2]. It is therefore necessary to develop an FC ageing model that takes into account operating conditions.
- **Faults propagation/evolution functions**, at a first stage under the hypothesis that no decision has been taken. This task will mainly focus on the dynamics of the different degradations and discrimination between the reversible and the irreversible one. Faults propagation laws will be developed in order to assess the impact of a given fault and its residence time on the SoH of the system. These laws will be integrated in the global ageing model.
- **Prognostics of the Fuel Cell System.** The prognostics of the Fuel Cell System will be based on hybrid approaches (model-based and data-based) already developed in the SHARPAC team [5, 6, 7]. Besides, the developed model should integrate all the point that have been raised above (different BoP components ageing, fault propagation, etc). The model should also be designed for a multi-stack system, where several stacks modules are combined differently into one power system.
- **Multistack system.** One of the objectives behind using a multistack approach is to extend the lifetime of the whole system by defining control strategies to commit the different individual stack according to their individual RUL and to the load profile.

Expected work:

Besides the bibliographic research (Task 1: M1 → M6), several tasks at short and mid-term are defined as follows:

- Task2 (M3 → M18). Experimentation on the BoP components.
definition of the testing protocols.
data generation.
- Task 3 (M9 → M18). Modelling and ageing/damage function.
Development of physical models for the components.
Generation of degradation maps using physical models for the components and generated data.
- Task 4 (M12 → M24). **Modelling and ageing/damage function of the Fuel cell stack and interaction of the individual components****Ageing.**
Assessment of the interaction between components.
Development of an ageing model of the Fuel Cell.
- Task 5 (M20 → M32). **Faults propagation/evolution functions.**
Comprehension of the degradation mechanisms of individual components.
Definition of the impact of degradations on the system.
- Task 6 (M24 → M36). **Prognostics of the Fuel Cell System.**
Reliable estimations of the SOH - State of Health and RUL - Remaining Useful Life.
Prognostic of the FC system including fault propagation.
- Task 7 (M32 → M36). **Multistack system.**
Extension of the RUL by defining power distribution between the individual stacks of the multi-stack system.

Existing supports

- St@rc (ongoing LABEX ACTION project) → long-duration testing.
- GIANTLEAP (ongoing EU FCH JU project) → expertise and BoP components ageing models.
- Test Bench ICARE-CSP (ANR Project) → long-duration testing of the compressor.
- Test Bench 1 kW PEMFC (existing facility) → long-duration testing of the humidification, cooling, ð

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Bibliography

- [1] Morando S., Jemei S., Hissel D., Gouriveau R., Zerhouni N., Proton exchange membrane fuel cell ageing forecasting algorithm based on Echo State Network, International Journal of Hydrogen Energy, Volume 42, Issue 2, 12 January 2017, Pages 1472-1480
- [2] Jouin M., R. Gouriveau, D. Hissel, M.-C. Péra, N. Zerhouni, Prognostics and Health Management of PEMFC - State of the art and remaining challenges, Int. J. of Hydrogen Energy, Vol. 38-35, pp. 15307-15317, 2013 ; DOI : 10.1016/j.ijhydene.2013.09.051.
- [3] Jouin M., R. Gouriveau, D. Hissel, M.-C. Péra, N. Zerhouni, Joint particle filters prognostics for PEMFC power prediction at constant current solicitation, IEEE Transactions on Reliability, 2015; DOI: 10.1109/TR.2015.2454499.
- [4] Silva R.-E., R. Gouriveau, S. Jemei, D. Hissel, L. Boulon, K. Agbossou, N. Yousfi Steiner, PEMFC degradation prediction based on Adaptive Neuro-Fuzzy Inf. Systems, Int. J. of Hydrogen Energy, Vol. 39-21, pp. 11128-11144, 2014; DOI: 10.1016/j.ijhydene.2014.05.005.
- [5] Morando S., S. Jemei, D. Hissel, R. Gouriveau, N. Zerhouni, ANOVA method applied to PEMFC ageing forecasting using an Echo State Network, *Mathematics and Computers in Simulation*, à paraître, 2015 ; DOI : 10.1016/j.matcom.2015.06.009.
- [6] Lechartier E., E. Laffly, M.-C. Péra, R. Gouriveau, D. Hissel, N. Zerhouni, Proton Exchange Membrane Fuel Cell behavioral model suitable for prognostics, Int. J. of Hydrogen Energy, Vol. 40-26, pp. 8384-8397, 2015 ; DOI :10.1016/j.ijhydene.2015.04.099.
- [7] Bressel M., Hilairet M., Hissel D., Ould Bouamama B., Extended Kalman Filter for prognostic of Proton Exchange Membrane Fuel Cell, Applied Energy, Volume 164, 15 February 2016, Pages 220-227
- [8] Petrone R., Yousfi Steiner N., Jemei S., Harel F., Hissel D., Péra Marie-Cécile, Model-based strategy oriented to PEMFC system prognostic for Bus transportation applications based on EMR formalism, International Conference on Fundamentals and Developpement of Fuel Cells, 31st of January 2017-2nd of February 2017, Stuttgart, Germany.
- [9] Operating Conditions control for extending PEMFC lifetime, Mezzi R., Yousfi Steiner N., Péra MC., Hissel D., Larger L., International Conference on Fundamentals and Developpement of Fuel Cells, 31st of January 2017-2nd of February 2017, Stuttgart, Germany.

