Journal of Power Sources 324 (2016) 745–757

Contents lists available at ScienceDirect

Journal of Power Sources

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

Prognostics of Proton Exchange Membrane Fuel Cells stack using an ensemble of constraints based connectionist networks

Kamran Javed [a, b, *], Rafael Gouriveau [a, b], Noureddine Zerhouni [a, b], Daniel Hissel [a, b]

[a] FEMTO-ST Institute (UMR CNRS 6174–UBFC, UFC, ENSMM, UTBM), Besançon, France
[b] FCLAB (FR CNRS 3539), Belfort, France

HIGHLIGHTS

- A data-driven ensemble is proposed for prognostics PEMFC stack.
- Ensemble is equipped with constraints to ensure predictions that enable prognostic.
- The ensemble strategy is generalized on rapid learning connectionist networks
- The proposed approach requires few learning data and has better consistency.
- Prognostics results show accurate predictions and less uncertainty.

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form
19 May 2016
Accepted 20 May 2016

Keywords:
Data-driven
Ensemble
Fuel cells
PEMFC
Prognostics
Remaining useful life

ABSTRACT

Proton Exchange Membrane Fuel Cell (PEMFC) is considered the most versatile among available fuel cell technologies, which qualify for diverse applications. However, the large-scale industrial deployment of PEMFCs is limited due to their short life span and high exploitation costs. Therefore, ensuring fuel cell service for a long duration is of vital importance, which has led to Prognostics and Health Management of fuel cells. More precisely, prognostics of PEMFC is major area of focus nowadays, which aims at identifying degradation of PEMFC stack at early stages and estimating its Remaining Useful Life (RUL) for life cycle management. This paper presents a data-driven approach for prognostics of PEMFC stack using an ensemble of constraint based Summation Wavelet- Extreme Learning Machine (SW-ELM) models. This development aim at improving the robustness and applicability of prognostics of PEMFC for an online application, with limited learning data. The proposed approach is applied to real data from two different PEMFC stacks and compared with ensembles of well known connectionist algorithms. The results comparison on long-term prognostics of both PEMFC stacks validates our proposition.

1. Introduction

A Fuel cell (FC) is an energy systems that offers clean and efficient way to generate electricity, which can run indefinitely as long as fed with hydrogen. The FCs are mainly classified on the basis of their electrolyte. Among different types of FCs, the Proton Exchange Membrane FC (PEMFC) is considered as the most versatile, which operates on low temperature (< 100 °C) and has the advantages of high energy density and low pollutant emissions [1]. Hence, it qualifies for stationary power generation, portable power generation, and power for transportation applications.

The PEMFC converts the chemical energy released during an electrochemical reaction of hydrogen and oxygen to electrical energy. Fig. 1a) shows a simplified unit cell, on the anode side the flowing in hydrogen splits into protons and electrons. The protons pass through the polymer electrolyte membrane towards the cathode side, while the electrons reach the cathode through an external circuit, producing electric energy in the meantime. The electrons entering the cathode side combine with the flowing in oxygen and the hydrogen ions (protons) arriving from the membrane to form water. Fig. 1b) shows a PEMFC stack of FCs connected in series through bipolar plates to increase the voltage of the stack. Fig. 1c) shows stack voltage drop signal over time.

Basically, the voltage drop indicates stack degradation as time grows. This degradation can be due to different factors like:

* Corresponding author.FEMTO-ST Institute (UMR CNRS 6174–UBFC, UFC, ENSMM, UTBM), 24 rue Alain Savary, F-25000 Besançon, France.
E-mail address: firstname.lastname@femto-st.fr (K. Javed).

http://dx.doi.org/10.1016/j.jpowsour.2016.05.092

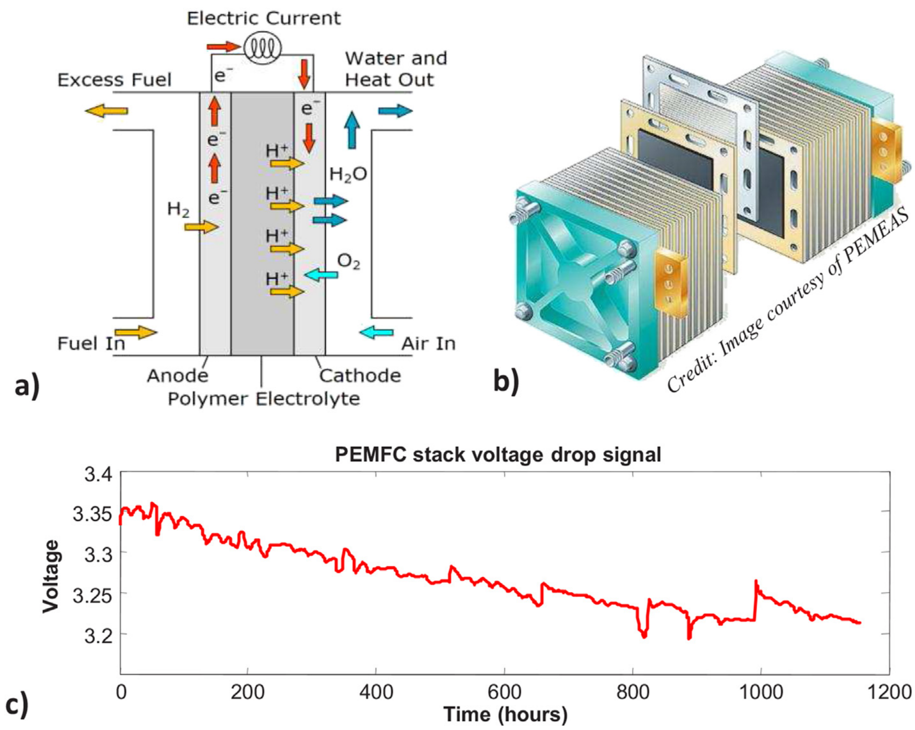

Fig. 1. a) PEMFC scheme, b) PEMFC stack, c) PEMFCs voltage.

material degradation, design and assembly. Moreover, the performance decay induced is strongly linked to the operating conditions (e.g. current load, operating temperature, air pollutants, etc.) [2]. In addition, the stack performance is constrained by the worst performing cell [3].

The methods to directly monitor stack degrading modes and their evolution are difficult to achieve [4]. Therefore, an indirect approach is adapted to monitor the FC/stack condition by observing voltage signal. Obviously, whatever the cause of degradation, it will result in a voltage drop and eventually the removal of the stack from service. In other words, the main barriers in commercialization of PEMFC technology are long-term performances, durability, and high maintenance costs [5]. Thus, ensuring FC stack service for a long period is of vital importance [3], which has led to Prognostics and Health Management (PHM) of FC systems, to enable improvements in their life management, use and support [6]. More precisely, the prognostics capability enables anticipating maintenance issues and proactive actions for a safe operation and timely decisions for equipment life cycle management. The FC prognostics requires mainly three steps.

1. Monitoring the state of health (SOH);
2. Predicting the aging process;
3. Estimating remaining useful life (RUL).

The FC systems (FCS) are highly multiphysics/multiscale, and it is difficult to access their internal parameters or to fully understand their degrading behavior. In other words, due to high complexity of FCS, development of accurate physics based prognostics is technically hard and expensive to realize [7]. Alternatively, data-driven prognostics does not require degradation process model and it can be deployed quickly without detailed understanding [8]. A data-driven approach learns directly FC/stack aging behavior from condition monitoring data (CM), e.g. current, temperature, voltage, etc., and use that knowledge to assess current state of FC/stack and to predict the evolution of its degradation to estimate RUL.

According to authors knowledge, only two data-driven approaches have been proposed so far for PEMFC prognostics namely, Adaptive Neuro-Fuzzy Inference System (ANFIS) [9] and Echo state network (ESN) [10]. Basically, the prognostics with ANFIS is achieved by predicting the stack voltage degradation using an iterative structure of ANFIS (i.e., the predicted value is used as a regressor). However, the iterative approach suffers from error accumulation problem with increasing prediction horizon. Also, the prognostics results from ANFIS model are based on single prediction, which is not reliable in the presence of uncertainty (from data or modeling). Moreover, ANFIS is based on slow iterative learning and its computational time increases with size of training data.

In [10], prognostics with ESN is not clearly demonstrated for RUL estimation. This work also used voltage to predict the degrading behavior of the PEMFC stack. However, the predictions are achieved with direct and parallel structures of ESN, that require prior knowledge of prediction horizon, which is not the case for prognostics. The ESN is a rapid learning approach, however, it requires several parameters to be set by the user. Moreover, due to lack of learning data/poor parameter initialization, ESN gives different solutions at each run. Therefore, single ESN model is not sufficient for prognostics. Consequently, the above issues with exiting data-driven approaches impact:

(a) robustness of the prognostics model, which makes it difficult to adapt degrading behavior of the stack due to poor consistency of the algorithm. Thus, RUL estimates will have large uncertainty, which will lead to wrong decisions;
(b) applicability of the prognostics model, because lack of data requires more complex models to fit the changing observations. Conventional data-driven approaches (e.g. ANFIS) are based on slow iterative tuning, and computationally expensive. Also such approaches require several parameters to be tuned by the user, which limits the ease of application.