



Sliding mode observer for proton exchange membrane fuel cell: automotive application



Maxime Piffard^b, Mathias Gerard^{a,b,*}, Ramon Da Fonseca^{a,b}, Paolo Massioni^c, Eric Bideaux^c

^a CEA LITEN, F-38054 Grenoble, France

^b Univ. Grenoble Alpes, F-38000 Grenoble, France

^c Laboratoire Ampère, INSA Lyon, Université de Lyon, 69621 Villeurbanne CEDEX, France

HIGHLIGHTS

- An observer is proposed to estimate the internal state of a PEMFC.
- This estimation can be performed with dynamical current and operating conditions.
- Performances are validated using a high-fidelity model running a WLTC.

ARTICLE INFO

Keywords:

PEMFC
Fuel cell management
State observer
Sliding mode observer

ABSTRACT

This work proposes a state observer as a tool to manage cost and durability issues for PEMFC (Proton Exchange Membrane Fuel Cell) in automotive applications. Based on a dead-end anode architecture, the observer estimates the nitrogen build-up in the anode side, as well as relative humidities in the channels. These estimated parameters can then be used at fuel cell management level to enhance the durability of the stack. This observer is based on transport equations through the membrane and it reconstructs the behavior of the water and nitrogen inside the channels without the need of additional humidity sensors to correct the estimate. The convergence of the output variables is proved with Lyapunov theory for dynamic operating conditions. The validation is made with a high-fidelity model running a WLTC (Worldwide harmonized Light vehicles Test Cycle). This observer provides the average values of nitrogen and relative humidities with sufficient precision to be used in a global real-time control scheme.

Nomenclature

λ_i	Membrane water content at the interface with i	[–]
λ_m	Membrane water content	[–]
ρ_{dry}	Dry membrane density	[kg·m ³]
e_m	Membrane thickness	[m]
EW	Equivalent weight of the membrane	[kg]
F	Faraday constant	[C·mol ^{−1}]
$F_{d,i}$	Back-diffusion flux of water	[mol·s ^{−1}]
F_{eo}	Electro-osmosis drag	[mol·s ^{−1}]
F_{in,H_2}	Inlet hydrogen flux in the anode	[mol·s ^{−1}]
F_{in}	Inlet flux of water in the cathode	[mol·s ^{−1}]
F_{out}	Outlet flux of water in the cathode	[mol·s ^{−1}]
$F_{X,p}$	Outlet flux of specie X during the purge	[mol·s ^{−1}]

I	Stack current	[A]
i	a for anode, c for cathode	[–]
K_{N_2}	Nitrogen permeation flux	[mol·s ^{−1} ·Pa ^{−1}]
$n_{X,i}$	Moles of specie X in the channel i	[mol]
P_i	Pressure in the channel i	[Pa]
P_{sat}	Saturation vapour pressure	[Pa]
P_{vap}	Partial vapour pressure	[Pa]
Q_{ao}	Purge command	[–]
R	Perfect gas constant	[J·K ^{−1} ·mol ^{−1}]
R_m	Membrane resistance	[Ω]
S	Membrane surface	[m ²]
T	Stack temperature	[K]
V_i	Volume of the channel i	[m ³]
$X_{X,i}$	Molar fraction of specie X in the channel i	[–]

* Corresponding author. CEA LITEN, F-38054 Grenoble, France.
E-mail address: mathias.gerard@cea.fr (M. Gerard).

1. Introduction

Proton Exchange Membrane Fuel Cell (PEMFC) seems to be the most suitable Fuel Cell (FC) technology for transportation applications, thanks to the high power density and the low operating temperature [1]. The remaining challenges to overcome before the widespread commercialization are the cost, durability and start-up, according to [2]. They can be improved either by materials improvements or by system optimization. For example, the dead-end anode (DEA) is a simple solution to run a fuel cell system with a reduced number of ancillaries. This also improves the fuel utilization as the hydrogen injected in the anode is supposed to be fully consumed, leading to a hydrogen efficiency close to 100%. However, the main drawback of the DEA is the presence of permeated nitrogen and liquid water in the anode side, that can only be removed of the channels by the outlet valve.

Several studies have analysed the issue of nitrogen and liquid water build up in the anode channels. According to [3], these species are responsible of a voltage drop as the stratification phenomenon tends to lower the hydrogen concentration in the outlet on the channels. This voltage drop is reversible, as the full voltage is recovered if the nitrogen and liquid water are purged from the anode. However, their presence could also lead to irreversible degradations, in particular the cathode carbon corrosion: the link between the carbon corrosion and the nitrogen build up in the anode has been studied by Ref. [4] during long purge intervals. Therefore, the DEA architecture is a solution to the cost issue but there is a need of an optimized purge procedure to minimize reversible and irreversible degradations from nitrogen build up.

The purge optimization has been studied in steady-state operations. For example [5] reports a trade-off between long purge intervals (responsible of carbon corrosion) and short ones (where the hydrogen loss is increased). A solution is given by taking into account the opening and closing time constants of the actuators. The optimization of the purge interval and duration is performed for a given operating power. However, this optimization is dependent of the operating conditions and it can not be applied to dynamic power. A second optimization has been made by taking into account the relative humidity in the channels [6]. Another optimization purge has been performed for a 90 kW automotive stack in recirculation mode by Ref. [7] to minimize the performance drop. In this case, the impact of nitrogen permeation on the performance is lower as the nitrogen is diluted in the hydrogen instead of accumulating in the outlet. The main drawback of these studies is that they can not deal with dynamic power and/or varying operating conditions. Adaptation to dynamic power is mandatory for automotive applications and varying operating conditions rather than steady-state conditions seems to be the next step of FC control. The publications [8–10] are some examples of the potential of dynamic operating conditions.

The design of such advanced FC control often requires the use of humidity measurements inside the stack. However, humidity sensors are expensive, have a poor durability and reliability and can only measure the relative humidity outside the stack, in the subsystems. A solution could be to build a diagnosis tool for flooding and drying of the cell based on a database, as in Ref. [11]. Another solution is to build a state observer to estimate the relative humidities in the channels, as in Ref. [12], where they estimate precisely the distribution of state parameters along the channels but rely on humidity sensors to correct the estimation.

The work presented here is based on a DEA architecture and proposes an observer to estimate the nitrogen in the anode side and the relative humidities in the channels. Only four types of sensors are used to correct the estimation: pressure, temperature, voltage and current. The objective is to provide a simple tool to generate additional measurements for a fuel cell management system. The observer is based on a simplified model which approximates a complex “2D+1D” model (more details are given in the next section). The observer convergence

is proved for dynamic operating conditions with Lyapunov theory. The estimation precision is validated using the complex “2D+1D” model with the desired output power extracted from WLTC profile.

A previous work with the same purpose has been presented in Ref. [13] with the UKF technique (Unscented Kalman Filter) for the observer instead of sliding mode. This UKF observer is difficult to tune for a specific (P, T) couple with no theoretical proof of convergence. The proposed observer is based on a more sophisticated state-space model and a different algorithm to overcome those issues. The extensive validation framework, using a wide range of dynamical operating conditions, disturbances and durability concerns, shows the effectiveness of this new approach versus [13].

2. Fuel cell model

2.1. General description

The fuel cell model used in this work is a model called MePHYSTO-FC, developed since several years and described in many studies [14–16] (previously called PS++ model).

It is a development platform including a 2D+1D multi-physic fuel cell model based on lumped and bond graph approach. It takes into account gas diffusion, two phases flow, heat transfer and electrochemistry. The complex in-plane serpentine flow field of the bipolar plates is modeled in 2D. The through-plane species transports are modeled in 1D (no in-plane transport in the GDL and catalyst layer). The model is used to calculate the local conditions and current distribution over the surface of the cell in response to dynamic operating conditions. Degradation mechanisms are added (by bottom-up of top-down approach) to calculate the fuel cell lifetime. An in-depth description of the actual model can be found in Ref. [16].

2.2. Membrane model

We recall here the main equations involved in the membrane transport species in our model. These equations are used in the observer. All the symbols are defined in the nomenclature.

The membrane water content λ_m is estimated with an integral term as:

$$\lambda_m = \int \left(\frac{EW}{\rho_{dry}} \frac{1}{e_m S} (-F_{d,a} - F_{e,o}) - (F_{d,c} + F_{e,o}) \right) dt$$

$$\lambda_m = \int \left(\frac{EW}{\rho_{dry}} \frac{1}{e_m S} (-F_{d,a} - F_{d,c}) \right) dt \quad (1)$$

The electro-osmosis and back-diffusion fluxes are calculated with [14]:

$$F_{e,o} = (1.0 + 0.028\lambda_m + 0.0026\lambda_m^2) \frac{I}{F} \quad (2)$$

$$F_{d,i} = \frac{\rho_{dry}}{EW} \frac{S}{e_m} (6.707 \cdot 10^{-8} \lambda_m + 6.387 \cdot 10^{-7}) \cdot \exp\left(\frac{-2416}{T}\right) (\lambda_m - \lambda_i) \quad (3)$$

with λ_i the membrane water content at the interface between the membrane and the electrode active area given by:

$$\lambda_i = 0.043 + 17.81a - 39.85a^2 + 36a^3 \quad (4)$$

where $a = P_{vap}/P_{sat}(T)$.

The model for the nitrogen permeation is taken from Ref. [4]:

$$K_{N_2}(\lambda_m, T) = \alpha_{N_2} (0.0295 + 1.21f_v - 1.93f_v^2) \cdot 10^{-14} \cdot \exp\left[\frac{E_{N_2}}{R} \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad (5)$$

with α_{N_2} a scale factor, E_{N_2} the nitrogen molar energy ($E_{N_2} = 24 \text{ kJmol}^{-1}$), $T_{ref} = 303 \text{ K}$ and f_v the volume fraction of water in

Download English Version:

<https://daneshyari.com/en/article/7725210>

Download Persian Version:

<https://daneshyari.com/article/7725210>

[Daneshyari.com](https://daneshyari.com)