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# Parameter Estimation Algorithm of H-100 PEM Fuel Cell

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## 1. Introduction

Polymer electrolyte membrane fuel cells (PEMFCs) have been recognized as one of the most promising eneygy conversion devices for commercial application due to their specific advantages, such as low operation temperature, zero pollutant emission, and high efficiency, etc [1]. Since PEMFC is a highly nonlinear system and some parameters are related to the operation condition, most existing models are difficult to accurately predict the PEMFC characteristics. Thus, it is necessary to exploit parameter estimation methods for PEMFC to online determine the unknown model parameters by using easily measurable data to obtain concrete models. Most of the parameter estimations schemes for PEMFC have been designed based on intelligent optimization techniques. However, optimization methods cannot address the estimation problem online since they focus exclusively on offline searching procedure, which introduces heavy computational costs in the practical implementation and thus cannot be used in the real-time applications. Therefore, this paper aims to exploit real-time adaptive parameter estimation methods for a nonlinear parametric PEMFC system.

## 2. Fuel Cell Model

### 2.1 Model Description and Problem Formulation

The PEMFC studied in this paper is an open-cathode fuel cell, which has been widely used. In previous works [2], [3], the modelling for this type of PEMFC has been addressed, which is considered the impact of water saturation. The electrochemical model of PEMFC, included ohmic losses, $V_{ohm}$, and activation losses $V_{act,c}$, can be expressed as:

$$V = \mathrm{n}_{cell}(E_r - V_{ohm} - V_{act,c}) \tag{1}$$

Specifically, the electrochemical active surface area, $ECSA$ is considered in the model of activation losses, which is highly dependent on the time-varying water saturation. This parameter is very difficult to measure and has certain impact on the voltage of PEMFC. Moreover, the ohmic resistance, $R_{ohm}$, in ohmic losses is considered as a constant in some models. However, the ohmic resistant is related to the operation temperature and the water transport in practice. Thus, the parameters to be estimated in this paper are selected as:

$$\theta = \begin{bmatrix} R_{ohm} & \frac{1}{ECSA} \end{bmatrix} \tag{2}$$

Since the estimated parameter $ECSA$ is embedded in the natural logarithmic function, the equation (1) can be formulated as follows

$$V = \mathrm{n}_{cell}\left[E_r - V_{ohm}(I, R_{ohm}) - V_{act,c}(I, T, ECSA)\right] = V(I, T, \theta) \tag{3}$$

Clearly, the above shown electrochemical model is a non-linear parametric system, which makes the existing real-time adaptive parameter estimation schemes invalid for (3). Our objective is to propose real-time adaptive parameter estimation algorithms for non-linearly parametric function of PEMFC (3), which allows us to estimate the unknown parameters of the ohmic resistance, $R_{ohm}$ and the electrochemical active surface area $ECSA$ through using the measurable variables (i.e. current $I$, temperature $T$, and voltage $V$)

## 3. Parameter Estimation Algorithm

The real-time adaptive parameter estimation method is exploited for a nonlinear parametric PEMFC system. Specifically, the Taylor series expansion is used to extract the unknown parameters from the electrochemical functions. Then, most recently proposed adaptive parameter estimation algorithm [4] is used to estimate time-varying parameters in the PEMFC model, where the convergence of estimation errors is guaranteed under the persistent excitation condition. Comparing to other classic estimation approaches relied on the predictor or observer errors with gradient descent algorithms, the main feature of the proposed method is that the adaptive law is driven by parameter estimation errors, which help guarantee fast the estimation performance even for the time-varying, nonlinearly parametric parameters.

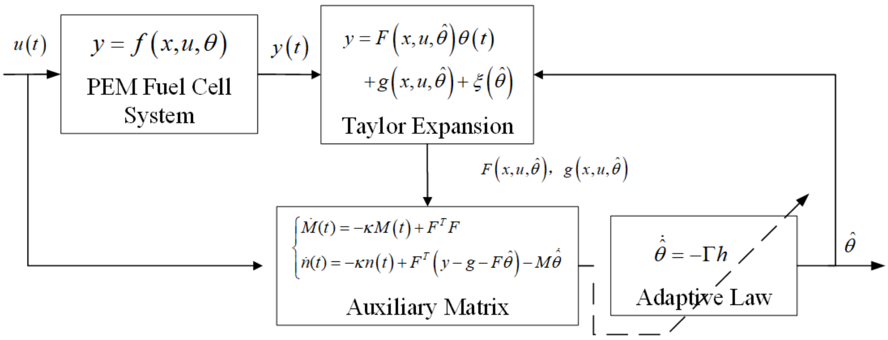


Figure. 1. Structure of the proposed parameter estimation scheme

## 4. Simulation Results

### *4.1 Experiment description and Model Validation*

The studied system is a H-100 open cathode proton exchange membrane fuel cell system. Figure. 2.a. shows a view of this fuel cell device as obtained from the distributor. In particular, the PEMFC stack is a self-humidified fuel cell with 20 cells and an active area of 22.5 cm2 per cell. Thus, the humidify system is not necessary in this system. Figure. 2.d. shows a schematic diagram of the system behaviour. A fan controlled through a pulse-width-modulation (PWM) duty cycle signal is used to force the air flow in the fuel cell, feed the cathode with the oxygen required for the reaction, and regulate the PEMFC temperature. The anode is fed with dry hydrogen coming from a hydrogen tank. Moreover, the original H-100 PEMFC is embedded in a case, where additional sensors are included (see Figure. 2.b.). The experiments are carried out inside a climatic chamber to obtain repetitiveness of the experiments (see Figure. 2.c.). The details of model validation have been addressed in [2], [3].

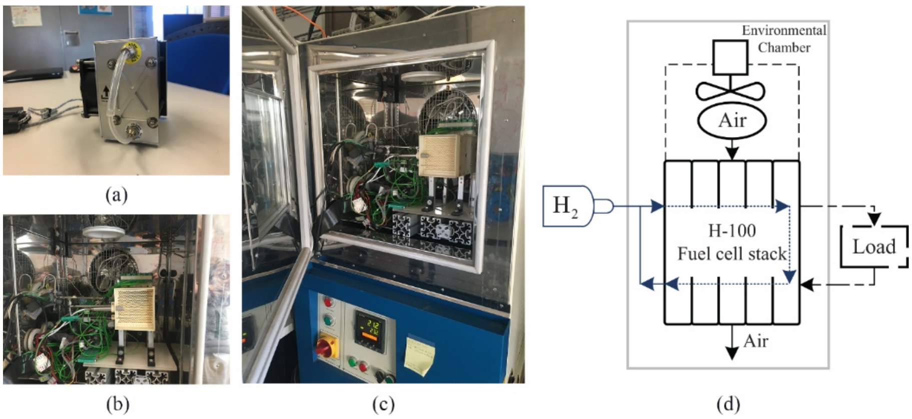


Figure. 2. Laboratory test rig: (a) Commercial H-100 PEMFC; (b) View of the H-100 PEMFC in the test rig system; (c) View of the environmental chamber; (d) Schematic diagram of the H-100 PEMFC system

### *4.2 Simulation Results*

In this section, the experiment is going to be taken into account to validate the parameter estimation algorithms. In this experiment, the fuel cell current is kept constant to $I = 3.95$ A while the fuel cell temperature changes due to a change in the fan speed. In this experiment the hydrogen is recirculated, and the purge mechanism is active to guarantee the enough quantity of hydrogen.

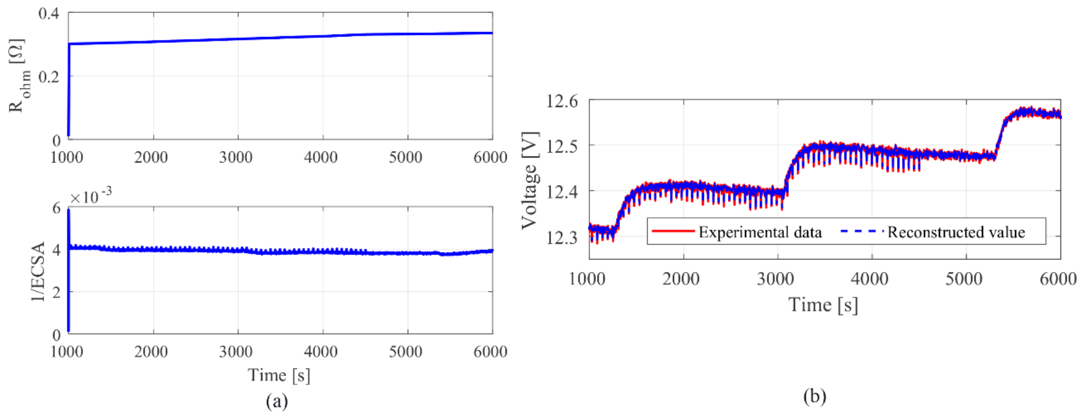


Figure. 3. Results: (a) Parameter estimation results for adaptive law; (b) The voltage outputs of the identified model with (15) and the experimental data

The profiles of the estimated parameters are depicted in Figure. 3.a. In order to show the improvement of the estimated results, the output voltage is reconstructed by using the collected temperature data and the estimated parameters, which is depicted in Figure. 3.b. It is clearly shown that the reconstructed voltage by using the estimated time-varying parameters provides an overall better model fitting performance in both the steady-state and transient, which implies that the fast-varying dynamics can be captured in this case. These results illustrate the validity of the proposed time-varying estimation scheme.

## 5. Conclustion

In this paper, a new adaptive parameter estimation method has been proposed to estimate relevant parameters in PEMFC with fast time-varying dynamics. The ohmic resistance and electrochemical active surface area are estimated. To handle the difficulty stemming from the nonlinear parametric property, the model is linearized by the Taylor series expansion. Moreover, to address the fast varying parameters, a new adaptive estimation method, independent of the widely used observer/predictor, is suggested. The proposed adaptive laws are directly driven by the parameter estimation error, and thus are able to achieve guaranteed fast convergence. Comparative experimental results illustrate the efficacy of the proposed estimation parameter methods. In the future work, we will extend the proposed parameter estimation approach to other kinds of fuel cell systems.


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