A Dynamic Ohmic Resistance Estimator of PEMFC Based on Dual Extended Kalman filter

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Abstract: Ohmic resistance is very important in the state observation of the proton exchange membrane fuel cell (PEMFC). A PEMFC model based on equivalent circuit and its time-discrete state space expression were established in this paper. The method of estimating the ohmic resistance of PEMFC based on the proposed model by using dual extended Kalman filters (DEKF) was introduced which is featured by simple computation and real time processing. Experiments indicated that the method proposed was very effective in the ohmic resistance estimation and the ohmic resistance could be estimated in real time with a high accuracy.

1. Introduction

In paper [1], Dachuan Yu etc. analyzed a stable model by an equivalent circuit including several diodes and BJT and a dynamic model composed by several capacitors and inductances. In paper [2], P. R. Pathapati etc. proposed a CKT model to describe the dynamic characteristics for PEMFC. Mo Zhijun etc. developed an on-line measurement for a general internal-resistance of fuel-cell stacks [3], however, there is some difference between the general internal-resistance and the ohmic resistance. Authors in paper [4] recruited a method to determine the ohmic resistance and studied the affection caused by different working conditions, whereas this method could not be used when the fuel cell stack works. In paper [5], a so-called alternating current variable frequency and variable amplitude method measuring the ohimic resistance was designed, which needs very complex software system and hardware system designs.

In this paper, based on a simplified equivalent circuit model, an ohmic resistance identification method using DEKF was proposed, which was proved to be effective and with a high accuracy during the tests.

2. PEMFC Modeling

2.1 PEMFC Model

Referred to [3], a simplified equivalent model of the PEMFC was shown in Fig.1.

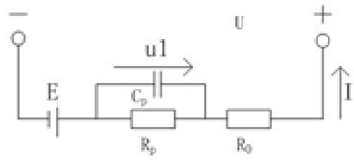

Fig.1 Simplified equivalent circuit model

In this model, R_0 represents the ohmic resistance, which describes the voltage jump caused by a sudden-varying current, the RC circuit consisting of a double-layer capacitor C_p and a resistance R_p describes the electro-chemical characteristics of the PEMFC caused by the surface pole structure, and E is a voltage which could be got from Fig. 2.

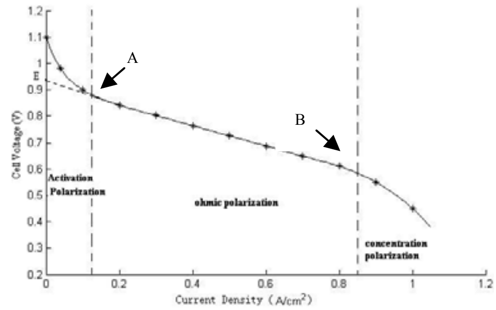

Fig.2 Polarization curve of PEMFC

2.2 State-space Expression of the Model

The state-space expression of the model is

$$\frac{du_1}{dt} = -\frac{1}{R_p C_p} u_1 + \frac{1}{C_p} I \quad (1)$$

$$U = -u_1 - IR_0 + E \quad (2)$$

This model could be expressed in a time-discrete form as

$$u_1(k+1) = A_1(k) u_1(k) + B_1(k) I(k) + w_k \quad (3)$$

$$U(k) = C_1(k) u_1(k) - R_0 I(k) + E(k) + v_k \quad (4)$$

in which, $A_1(k)=e^{-\frac{T}{R_pC_p}}$, $B_1(k)=R_p(1-e^{-\frac{T}{R_pC_p}})$, $C_1(k)=-1$, and w_k, v_k are the process noise and sensor noise of the system respectively. w_k describes the noise caused by the inaccurate model or other unknown input of the system, v_k describes the noise caused by the sensor.

3. Resistance Estimation Based on DEKF

3.1 DEKF Resistance Estimator[6-8]

If we define the parameter vector of the model as

$$\theta=[R_0 \quad C_1 \quad R_1 \quad E]^T,$$

and the dynamic characteristics of the parameters are expressed as

$$\begin{cases}\theta(k+1)=\theta(k)+r_k \\ U(k)=C_2(k)\theta(k)-u_1(k)+E(k)+e_k\end{cases},$$

$$\begin{aligned}&C_2(k)=[-I(k) \quad a \quad b \quad 1] \\ &a=(\partial U(k)/\partial u_1(k))\times(\partial u_1(k)/\partial C_1(k)) \\ &b=(\partial U(k)/\partial u_1(k))\times(\partial u_1(k)/\partial R_1(k))\end{aligned},$$

and varying of the parameters is driven by some little noise r_k, the sensor noise of the parameter estimator is described by the noise e_k, here let $Q_r=E(r\times r^T)$, $Q_e=E(e\times e^T)$, then the whole dual extended Kalman filter is summarized as following equations. Generally, the principle of the DEKF is shown in Fig. 3.

$$P_\theta(k|k-1)=P(k-1|k-1)+Q_r \tag{5}$$

$$A_1(k-1)=\exp(-\frac{T}{R_1(k-1)C_1(k-1)}) \tag{6}$$

$$B_1(k-1)=R_1(1-A_1(k-1)) \tag{7}$$

$$u_1(k|k-1)=A_1(k-1)u_1(k-1|k-1)+B_1(k-1)I(k-1) \tag{8}$$

$$P(k|k-1)=A_1(k-1)P(k-1|k-1)A_1(k-1)^T+Q_w \tag{9}$$

$$K(k)=P(k|k-1)C_1^T(k)[C_1(k)P(k|k-1)C_1^T(k)+Q_v]^{-1} \tag{10}$$

$$u_1(k|k)=u_1(k|k-1)+K(k)[U(k)-C_1(k)u_1(k|k-1)+R_0I(k)-E(k)] \tag{11}$$

$$\theta(k|k-1)=\theta(k-1|k-1) \tag{12}$$

$$P(k|k)=(I-K(k)C_1(k))P(k|k-1) \tag{13}$$

$$K_\theta(k)=P_\theta(k|k-1)C_2^T(k)[C_2(k)P_\theta(k|k-1)C_2^T(k)+Q_e]^{-1} \tag{14}$$

$$\theta(k|k)=\theta(k|k-1)+K_\theta(k)[U(k)-C_2(k)\theta(k)+u_1(k)] \tag{15}$$

$$P_\theta(k|k)=(I-K_\theta(k)C_2(k))P_\theta(k|k-1) \tag{16}$$

3.2 Initialization of the Algorithm

Initialization of R_0 was determined by the slope of the line A-B in Fig.2, and its value was about 1Ω. Time constant $\tau=R_pC_p$ and R_p could be determined by a voltage response of a current pulse [9], and $u_1(0|0)$ was set to be 0 at first. P and P_θ describe the uncertainties of the initial states and initial parameters, while Q_e and Q_r decide the correcting of the prediction. According to the real condition, we can adjust the P and Q by analyzing the sensor noise and the process noise.

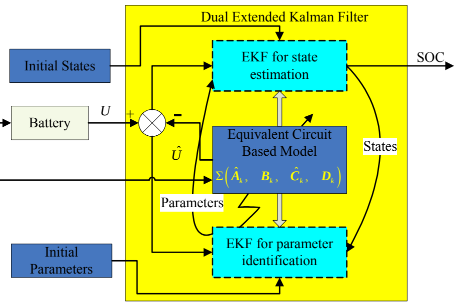

Fig. 3 General Principle of DEKF

4. Tests and Results

Two different tests were implemented. The first one composed of several different current pulses (Fig.4). This test was implemented on a test bench. The second test was a current profile we got when the vehicle was running, and current profile was shown in Fig.5.

Fig.4 shows that, ohmic resistance changes with the varying of the current, and larger current leads to smaller ohmic resistance. When current is large, there is more water generated on the anode of the stack, and the humility of the membrane rises, which introduces a smaller ohmic reistance. Fig.5 is the voltage comparison between the model and the actual stack.

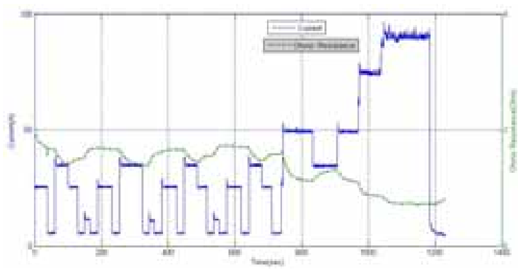

Fig.4 Ohmic resistance versus current on the test bench

From Fig.6, we can also see the resistance changing caused by the working conditions. In a regular condition, as the current loading on the stack, and with a good humility control, the ohmic resistance reduces to a stable value.

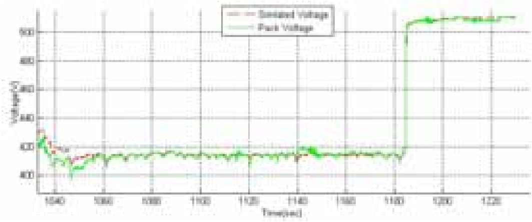

Fig.5 Voltage comparison between the model and actual stack on test bench

Fig.7 shows the voltage comparison of the model and the actual stack, which proves the accuracy of the model and the parameter estimation.

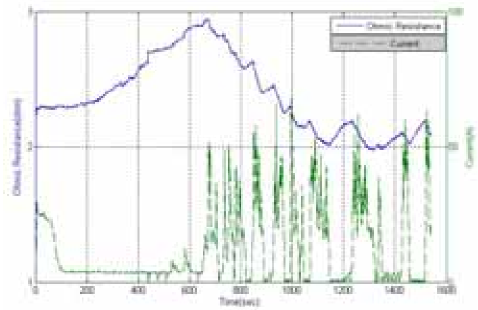

Fig.6 Estimated ohmic resistance versus current on vehicle

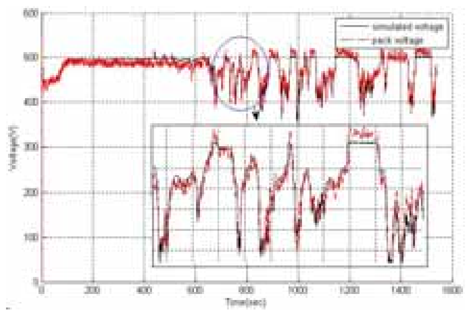

Fig.7 Voltage comparison between the model and actual stack on vehicle

5. Conclusions

A. The proposed method based on the equivalent circuit model and the dual Kalman filter was very effective in the ohmic resistance estimating of the PEMFC. Testing results show the high accuracy of the estimation;

B. The complexity of the algorithm is not very high, which introduces a low cost in the algorithm implementation. This method could be implemented on the platform of MCU or DSP easily.

C. Although in this paper, only the ohmic resistance estimation of the PEMFC was introduced, the method could applied to estimate other parameters very well in a similar pattern with little adapting.

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