NOVEL SLIDING MODE CONTROL FOR THE AIR MANAGEMENT SYSTEM OF FUEL CELL ENERGY SYSTEM

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Summary

Proton exchange membrane fuel cell (PEMFC) has the advantages of clean, high efficiency and environmental protection. Aiming at the optimal oxygen excess ratio control of the system under the complex and changeable conditions, a fourth-order nonlinear system mathematical model for the air supply system of PEMFC stack is developed by Simulink. A new nonsingular terminal sliding mode controller is proposed to control the OER (oxygen excess ratio) of the system, adjust the excess oxygen and prevent hypoxia. The results show that compared with the traditional linear sliding mode controller, the designed controller has lower delay and response time for sudden change. Furthermore, the new sliding mode structure will achieve finite time convergence and solve the problem that the traditional terminal sliding mode has singular points. This novel control method effectively improves the efficiency, stability, and reliability of the PEMFC system.

Keywords: Stack structure design; 3D modeling of large scale stack, stack with realistic structure, Multi-physics simulating.

Text

According to climate change, major energy transformation needs to start from many aspects. On the one hand, it needs to strengthen the development and utilization of the renewable energy to decarbonize, and reduce the environmental pollution [1]. On the other hand, the promotion of electrification can improve energy efficiency and facilitate more use of clean energies. Meanwhile, the energy-saving technologies and improved processes should be adopted to coordinate the use of clean energy and further optimize the energy structure.

Methanol and hydrogen energy are two of the alternative fuels with relatively high combustion efficiency and low carbon content, which are widely used and considered as the potential energy carrier medium [2]. In the context of the current energy crisis, hydrogen energy is considered to be one of the most potential secondary energy [3]. Hydrogen energy is rich in reserves and widely distributed, accounting for the largest proportion of elements on the earth. It has high combustion calorific value and pollution-free combustion, and is an ideal energy medium for sustainable development. However, we should not be in a hurry to develop more applications that use hydrogen energy, because the technological innovation and policy support are also essential. Oxyhydrogen fuel cells can generate electric energy by reacting the hydrogen contained in the cells with oxygen in the air. This kind of electric energy is generated through electrochemical reaction, which makes its energy conversion efficiency at a high level. Furthermore, it has many advantages, such as, higher energy density, lower vibration noise and zero emission [4,5]. PEMFC are widely used as a kind of mature fuel cells, such as, marine and automotive [6-8]. However, the PEMFC is still limited in its wide application due to its high cost and short service life. Therefore, it is very necessary to improve the service life and reduce the use cost through the advanced system controlling technology. Among them, too much or too little oxygen in the supply system will greatly affect the performance efficiency of the PEMFC stack and even cause damage to the stack structure. The air supply system has received more and more attentions and considered to be a hot and difficult point to determine the PEMFC system performance and duration.

However, it is necessary to note that although most of the above works had greatly increased our understanding on the sub-system controlling of the fuel cell system and had achieved varying degrees of success, the controllers do not fully consider the uncertainty of disturbance in tracking performance. Furthermore, these systems were asymptotically stable to varying degrees with certain setting time of system response. Based on this, this paper proposed a novel sliding mode controller, which can make the system converge in finite time, greatly eliminate the delay time, and enhance the robustness and anti-interference ability of the PEMFC system. Meanwhile, the new sliding mode control method would also solve the key problem that the terminal sliding mode control rate has singular points [9].

Four-state PEMFC system model

PEMFC system is mainly composed of the subsystems, such as the supply system, reactor system, thermal management system, etc. These subsystems work together to complete the energy conversion and control tasks. In this paper, it is determined that enough compressed hydrogen, ideal humidification, and temperature can be obtained before the gas enters the stack. Thus, the influence of other factors on the air supply can be eliminated.

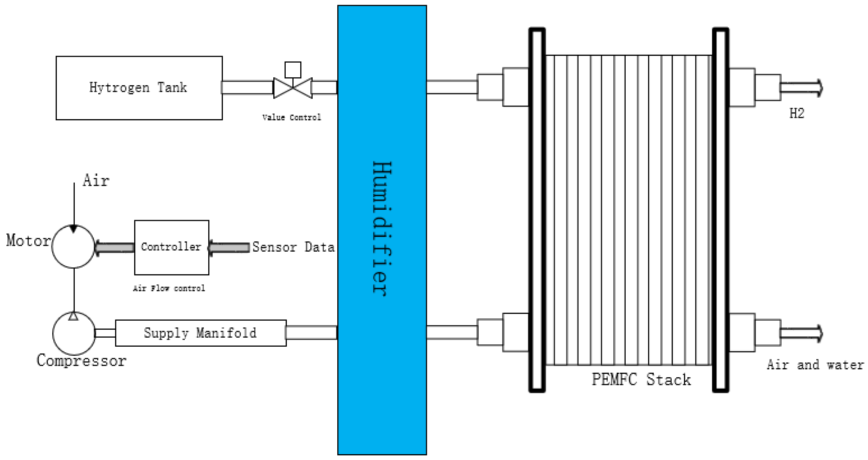

Figure 1 Sketch diagram of a typical PEMFC system.

According to the nine-state quantity model, this paper adopted a simplified model of a state equation with four state parameters [16, 29]. **Fig. 2** show the air management system. The fourth-order nonlinear spatial state equations can be described as,

$$\dot{X}_1(\mathrm{t}) = \mathrm{q}_1(X_4(t) - (X_1(t) + X_2(t)) - \mathrm{q}_2) - \frac{\mathrm{q}_3 X_1(t)\omega_1(t)}{\mathrm{q}_4 X_1(t) + \mathrm{q}_5 X_2(t) + \mathrm{q}_6} - \mathrm{q}_7\omega_2(t), \quad (6)$$

$$\dot{X}_2(\mathrm{t}) = \mathrm{q}_8(X_4(t) - (X_1(t) + X_2(t)) - \mathrm{q}_2) - \frac{\mathrm{q}_3 X_2(t)\omega_1(t)}{\mathrm{q}_4 X_1(t) + \mathrm{q}_5 X_2(t) + \mathrm{q}_6}, \quad (7)$$

$$\dot{X}_3(\mathrm{t}) = -\mathrm{q}_9 X_3(t) - \frac{\mathrm{q}_{10}}{X_3(t)}\left(\left(\frac{X_4(t)}{\mathrm{q}_{14}}\right)^{\mathrm{q}12} - 1\right)Y_3(t) + \mathrm{q}_{13}u, \quad (8)$$

$$\dot{X}_4(\mathrm{t}) = \mathrm{q}_{14}\left(1 + \left(\mathrm{q}_{15}\left(\frac{X_4(t)}{\mathrm{q}_{11}}\right)^{\mathrm{q}12} - 1\right)\right)(Y_3(t) - \mathrm{q}_{16}(X_4(t) - (X_1(t) + X_2(t)) - \mathrm{q}_2) \;, \quad (9)$$

where u is the control input. q_1 to q_{24} are constant coefficients which are collected in **table 1**. X_1 to X_4 are the four state quantities of the system. X_1 is the cathode oxygen pressure, X_2 is the cathode nitrogen pressure, X_3 is the rotational speed of the motor shaft, X_4 is the manifold pressure. The output of the system: Y_1 for the stack voltage V_{st}. Y_2 is same as $X4$, Y_3 is the intake air flow. Y_3 can be calculated as,

$$Y_3(t) = \frac{y_3^{max}}{x_3^{max}}\left(1 - \exp\left(\frac{-r_0\left(\frac{X_3^2(t)}{r_2}\right) - X_4(t)}{r_1 + \frac{X_3^2(t)}{r_2} x_4^{min}}\right)\right). \quad (10)$$

Oxygen excess ratio (OER) is the ratio of the incoming oxygen flow to the actual oxygen flow consumed. Insufficient oxygen supply will lead to extremely high concentration polarization and oxygen starvation. Oxygen starvation of long term will seriously decline the reliability and life of the PEMFC stack. Thus, inject excessive oxygen or air is required.

In order to meet the above control requirements, the OER is maintained at its optimal value by an effective controller. In this section, this new variable structure sliding mode control method is introduced to obtain fast tracking degree and accurate tracking effect. The control block diagram of the system is shown in **Fig. 3**.

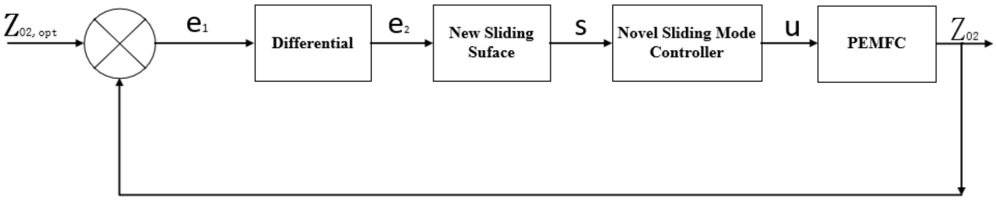

Fig. 2 The control block diagram of the system.

Fig. 3 shows the changes of four state parameters with times. They are cathode oxygen pressure, cathode nitrogen pressure, compressor motor speed and supply manifold pressure. These four figures show that the four parameters change accurately with the change of the stack electric current, and also indirectly prove the response of the excess oxygen ratio.

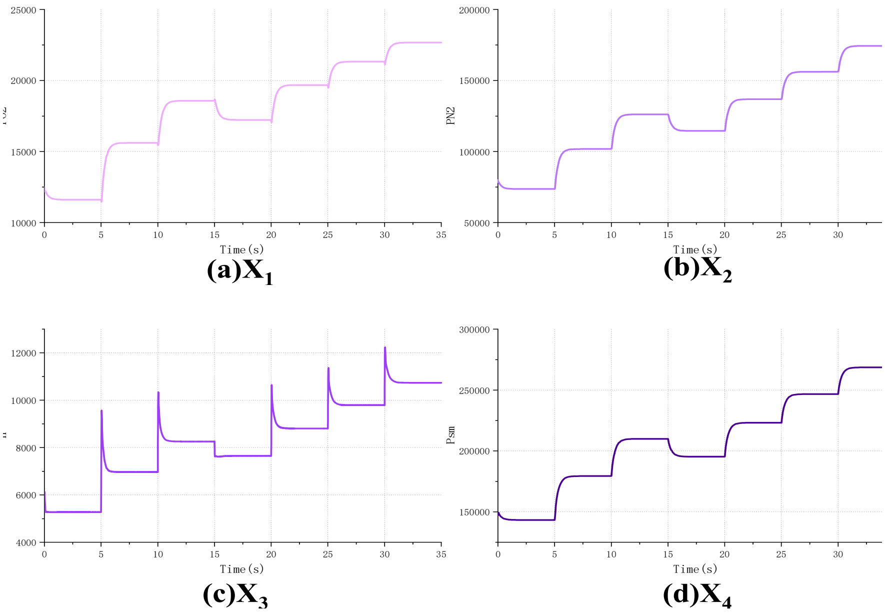

Figure 3 Four state parameters.

In this paper, a new sliding mode controller is designed to adjust the OER for the air management system of a typical PEMFC system to adapt to the current change. Parts of the conclusions can be concluded as follows, i) Compared with the asymptotic stability achieved by the ordinary sliding mode controller, this new variable structure sliding mode controller will achieves finite time convergence. Ii）The new sliding mode controller will have fast response and tracking adjustment for the electric current mutation. The overshoot of the control target OER control is almost the same as that of the ordinary sliding mode, and the overshoot of some results is slightly higher, which has no effect on the results. Iii）The new variable structure sliding mode controller is obviously superior to the ordinary sliding mode observer in the key performance indicators, and has the advantages of stronger robustness and anti-interference ability. This is precisely because the new sliding mode controller introduces a nonsingular sliding mode encapsulation structure, which makes the sliding mode surface more stable than the ordinary sliding mode. Iv）In this paper, a new and more efficient method for the future fuel cell air management is proposed, which aims to make a small step for the decarbonized future energy.

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ANALYSIS OF DIRECT METHANOL-BASED SOLID OXIDE FUEL CELL SYSTEM

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Summary

In this wrok, model No. 57 will be used as a basis for constructing a fuel cell system with thermal energy recycling using a combination of industrial process software Aspen Plus and Comsol, where the fuel exhaust and air exhaust emitted from the cell will be used for preheating the inlet fuel in order to seek the thermal balance of the system and maximize the output power.

Keywords: DM-SOFC; Tubular solid oxide fuel cells; waste heat recovery; Fuel Cell System Design;