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Study on the control mode of proton membrane fuel cell system

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Abstract: In the era of energy shortage, proton membrane fuel cell using hydrogen as energy source has attracted great attention because of its advantages of zero emission and high energy conversion efficiency. Hydrogen supply system is an important part of fuel cell system. Efficient hydrogen supply system can improve hydrogen utilization rate and relieve anode flooding and hydrogen hunger with optimal exhaust drainage time. At the same time, the pressure difference between cathode and anode must be maintained within a certain range when proton membrane fuel cells are running. Reasonable pressure control algorithm can improve the safety and stability of proton membrane fuel cells. In this paper, based on the model of the total fuel cell system, the anodic fuzzy PID pressure control algorithm and the cathode fuzzy PID pressure following control algorithm for proton membrane fuel cells are designed, and the effectiveness of the fuel cell pressure control algorithm is studied through simulation analysis.

Keywords: Fuel cell pressure system; Variable domain fuzzy PID; Pressure following control.

1. Introduction

At present, in the control research of proton membrane fuel cell system, most of the research results are the separate analysis and control of different subsystems and different parameters, and most of the control methods are PID control and fuzzy control algorithm, and the control methods and means are relatively simple.

Fawad.R.M.et alestablished the integrated dynamic model of the fuel processor and fuel cell reactor, and maintained the hydrogen flow of the fuel cell reactor at the set value by combining PI and PID controller. Heng Bao.et.al[2, 3]establishes the fuel cell nonlinear system model, and designs linear and nonlinear multivariable controllers for air flow and hydrogen flow with recirculation, which improves the optimal peroxide ratio of air, the transient response of cathode inlet pressure and the pressure difference between cathode and anode, and improves the anti-interference performance of the system. Jinglin He.et al Uses circulating fan and vacuum ejector to build hydrogen circuit of proton exchange membrane fuel cell system, and uses PID controller and state feedback controller to study hydrogen pressure and excess ratio. On this basis, the optimal state feedback controller and observer are designed to control the hydrogen pressure and excess ratio coefficient. The algorithm is further designed by linearizing the nonlinear state equation. Anh,J W.et altotal fuel cell system including air, hydrogen, water and heat management system is established. A fuel cell stack dynamic model considering non-isothermal two-phase effect is established. A feedback controller with integrator and observer is adopted to improve control performance. Based on the dynamic model, Matraji,Imad.et alestablished a two-order synovium multi-input multi-output controller based on torsion algorithm and a fuel cell nonlinear dynamic model, and verified that the controller has a good transient response and can keep the pressure difference between cathode and anode stable.

2. Fuel cell pressure system model

In this chapter, the model of fuel cell power system is established by combining the previous research results and the mathematical and physical formula model of corresponding components. Meanwhile, nitrogen gas transmembrane penetration model and anode waterflooding model are considered to simulate the actual working situation of fuel cells more truly. The anode hydrogen circuit model mainly includes the proportional valve model, hydrogen cycle model, tailgate valve model, drainage valve model and fuel cell hydrogen consumption model. Cathode oxygen circuit model mainly includes air compressor model, fuel cell oxygen consumption model, back pressure valve exhaust model. It also includes gas transmembrane permeation model and hydrate transmembrane permeation model (anodic waterflooding model). By combining the equations of the above models and building the subsystem model of proton membrane fuel cells based on Simulink, it simulates the real working situation of proton membrane fuel cells, and provides the foundation for the subsequent controller design. The modeling and simulation diagram of the fuel cell pressure system is shown in Figure 1.

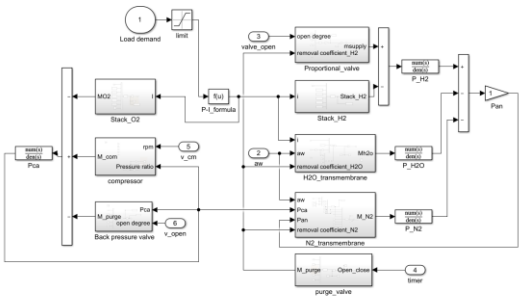


Fig. 1 Fuel cell pressure system model

3. Pressure control method design

The control system is the core of the proton membrane fuel

cell system. A perfect control system can ensure the safety and stability of the proton membrane fuel cell, improve the efficiency of the system, and efficiently provide energy for the equipment. The operation of fuel cell is controlled by humidity, temperature, pressure and other parameters. Pressure is a major factor affecting the operation of the proton membrane fuel cell system, and it is also a parameter that has a great relationship with each component in the system. For example, in the fuel cell, the hydrogen supply valve has the input hydrogen flow rate, the back-pressure valve has the output air flow rate, and the fuel cell has the consumption reaction gas flow rate, all of which can be converted into pressure by the formula. Therefore, effective control of the pressure value can effectively control the fuel cell system. Different pressure values will affect the working efficiency of fuel cells. 2bar proposed in the previous article is used as the pressure value of the anode of fuel cells. Meanwhile, the normal operation of fuel cells requires that the pressure difference between the cathode and anode of proton film ranges from 0.15 to 0.3bar. Thus increasing the safety risk of fuel cell system. Therefore, it is necessary to control the system pressure of fuel cell.

When the proton membrane fuel cell control proportional valve controls the anode pressure, the hydrogen cathode also needs to follow the corresponding pressure control, in order to ensure that the pressure on both sides of the proton membrane is kept within a reasonable range, to ensure the safety of the fuel cell system. Therefore, two controllers need to be designed, namely anode pressure control and cathode pressure following control. The system control objectives are shown in Figure 2.

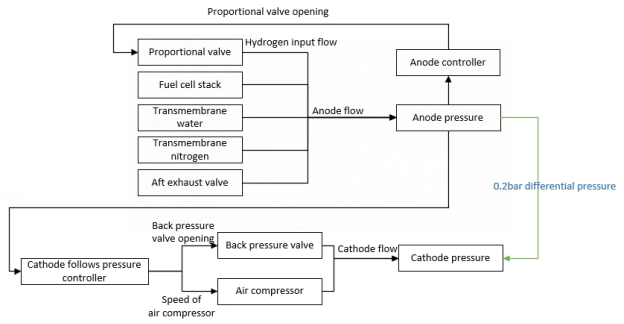


Fig. 2 System pressure control diagram

4. Pressure control algorithm design

4.1. Design of fuzzy PID controller for fuel cell cathode

1. Identify fuzzy subsets

The input variables selected by this system are error e and error change rate ec, and the output variables are the changes of kp, ki and kd of PID controller. The language of fuzzy subset of input and output variables is {NB (negative large), NM (negative medium), NS (negative small), ZO (moderate), PS (positive small), PM (middle), PB (CP)}.

2. Determine the domain and membership function of fuzzy subset

The maximum pressure range of the system design is 3bar, so the basic analects of error e of the fuzzy controller in the variable domain is [-3,3]. The basic domain of fuzzy controller error change rate ec obtained when PID controller controls the pressure of fuel cell system is [-3,3], quantization factor Ke is, Kec is. The domain of parameters kp, ki and kd is set to [-0.5,0.5]. Select the common triangular membership function.

3. Establish fuzzy controller control rules

Fuzzy control rules are the core part of fuzzy control, in this system is mainly based on the principle of the system and relevant experience to summarize and formulate, commonly used fuzzy rules establishment methods have observation method, expert experience method, fuzzy model method and other three methods.

The three parameters of the fuzzy PID controller are adjusted as follows:

1) when the | e | large, for the sake of the system can achieve the effect of fast track, so choose the larger Kp [34]; At the same time, in order to avoid the change rate of deviation is too large, the differential action should be inhibited to prevent its rapid increase, and the small Kd should be selected. In order to prevent integral saturation and excessive overshoot, Ki is generally set as zero.

2) when the | e | and | | ec for the medium size, in order to avoid overshoot is bigger, so choose smaller Kp, also can choose smaller Ki; In order to ensure the fast response of the system, appropriate Kd is selected.

3) when the | e | is small, in order to the stability of the system can achieve good control effect, choose the larger Kp and Ki; At the same time in order to avoid the system oscillations, and improve the anti-interference ability, in the | | ec is lesser, can choose larger Kd, | | ec is bigger, the smaller the Kd.

According to the above principles, the fuzzy rule table can be designed as follows

Table. 1 Fuzzy control rules

Δkp / Δkd / Δki	E						
EC	NB	PB	PB	PM	PM	PS	ZO	ZO
	NM	PB	PB	PM	PS	PS	ZO	NS
	NS	PB	PM	PM	PS	ZO	NS	NS
	ZO	PM	PS	PS	ZO	NS	NM	NM
	PS	PS	PS	ZO	NS	NS	NM	NB
	PM	PS	ZO	NS	NM	NM	NM	NB
	PB	ZO	ZO	NM	NM	NM	NB	NB

4. Fuzzy reasoning and unambiguities

Mamdani fuzzy inference method is used in the system. Mamdani fuzzy inference method uses minimum operation rules to define the fuzzy relation expressed. The statement relation can be expressed as R: If x is A then y is B. Where, x is the language variable input by the controller, and A is the fuzzy set; y is the output language variable, B is the fuzzy set of output, RC represents the fuzzy relation, which can be expressed by the following formula:

$$R_c = A \times B = \int_{x,y} u_A(x) \wedge u_B(y) f(x,y) \quad (1)$$

The fuzzy quantity obtained by fuzzy reasoning is the weighted average method. After obtaining the exact value, it is necessary to multiply with the scale factor to get the actual output value of the control system.

According to the above adjustment principles, the parameters can be derived into formula (2) to achieve control.

$$kp = kp_0 + \Delta kp$$
$$ki = ki_0 + \Delta ki \quad (2)$$
$$kd = kd_0 + \Delta kd$$

The design and simulation of fuzzy PID controller for back pressure valve is shown in Figure 3:

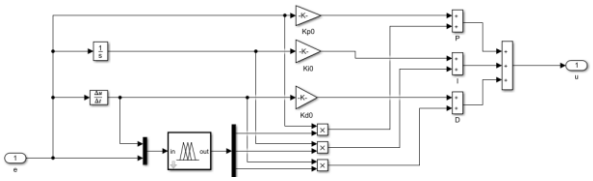


Fig. 3 Back pressure valve pressure fuzzy PID controller

The fuzzy PID controller established for air compressor is the same as the above fuzzy controller design method. Because air compressor is designed for flow control, it is finally converted into pressure to ensure that the whole cathode pressure is followed by control, so it only needs to choose different discussion domains:

According to studies, the optimal peroxide ratio of fuel cells is generally 1.51.5. According to the fuel cell cathode oxygen consumption system, it is calculated that the oxygen mass flow rate of the cathode under the condition of maximum current is 12.65g/s, the ec set domain is [-13,13], and ec the domain of is [-13,13].The rest of the parameter values and domains are consistent with the pressure control PID controller based on the back pressure valve above. The design and simulation of air compressor flow fuzzy PID controller is shown in Figure 4.

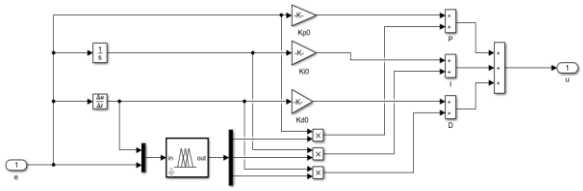


Fig. 4 Fuzzy PID controller for air compressor flow

4.2. Design of the variable domain fuzzy PID controller for fuel cell anode

The design of the fuzzy PID controller of the variable domain in this system refers to the fuzzy PID controller of the design, again on the basis of only the scope of the domain to re - specify, and then set the scaling factor. The scaling factors selected are as follows:

$$\alpha(x) = 1 - 0.98e^{-0.8x^2} \quad (3)$$

The design of fuzzy PID controller in anodic variable argument domain is shown in Figure 5. Because the fuzzy controller cannot change the analects in the software, simulation modeling of fuzzy controller in variable argument domain is carried out by writing code and inputting S function.

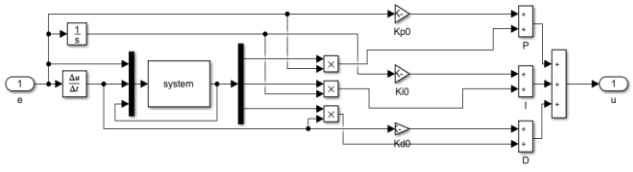


Fig. 5 Fuzzy PID controller in anode variable domain

5. Pressure control simulation results analysis

5.1. Control system model

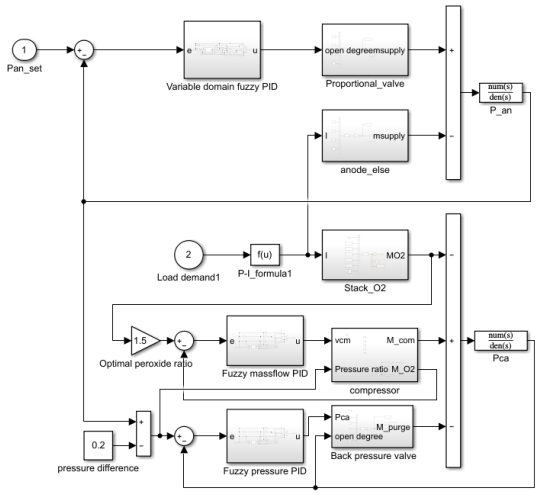


Fig. 6 Control system model

5.2. Pressure follows data analysis

For the control effect of pressure, the control effect of PID control algorithm can be verified by comparison. FIG.7shows the effect diagram of voltage boost control at startup time. FIG.8shows the following effect diagram of cathode pressure when anode pressure fluctuates. FIG.9shows the control effect diagram of cathode pressure following when the system pressure is fixed and the reactor power is adjusted.

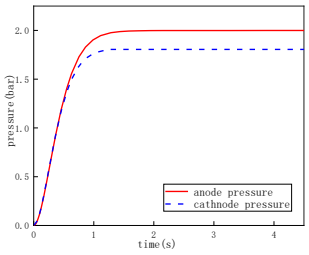


Fig. 7 Boost the voltage at startup time

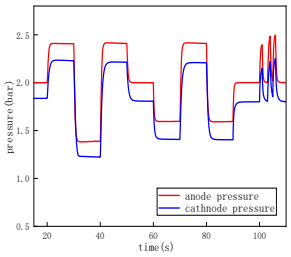


Fig. 8 Pressure fluctuation follows pressure

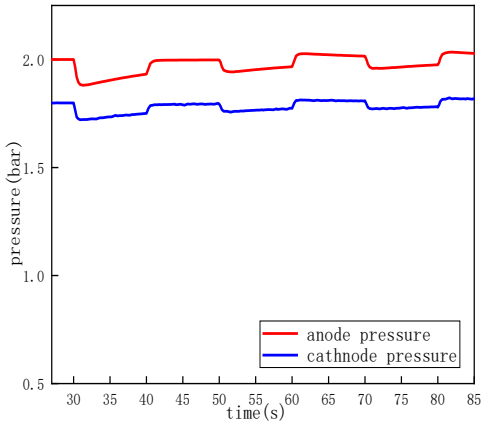


Fig. 9 Power fluctuation under pressure to follow

As can be seen from the figure above, the pressure control algorithm designed in this paper has a good control effect. In the process of pressure boost, the pressure difference does not exceed 0.3bar and is maintained within a safe range. Under the condition of anode pressure fluctuation, the cathode pressure follows well and is also within the normal range of

pressure difference. In the case of power load variation, the anode pressure variation is also within the normal range.

6. Conclusion

As can be seen from the simulation results of the anode pressure controller and the cathode pressure following controller, the controller designed in this paper not only has a good control effect on the anode pressure, but also has a good control effect on the cathode pressure following control, which can keep the cathode and anode pressure within the normal range. It is helpful to study the safety strategy of fuel cell system.

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