Genetic Algorithm PID Control of Solid Oxide Fuel Cell

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Abstract. In this paper, a genetic algorithm PID controller is designed to control the output voltage of SOFC single battery. The genetic algorithm is adopted and designed to optimize the parameters of standard PID controller $K_P$, $K_I$ and $K_D$, so that the difficulties in parameters setting of PID are solved. The simulation results show that the designed genetic algorithm PID controller for the voltage of SOFC single battery can achieve certain and required accuracy as well as fast response speed.

1. Introduction

Fuel cell is a new generation of power generation technology after hydropower generation, thermal generation and atomic generation [1]. Because its power generation process is not restricted by the Carnot cycle and no other mechanical transmission components, it has the advantages of quiet, pollution-free, high energy efficiency [2].

In 2014, So-Ryeok Oh and Jing Sun analyzed the static and dynamic characteristics of the 5-kilowatt class solid oxide fuel cell and gas turbine combined system under thermal constraints, and proposed a model prediction controller based on state constraints and input constraints. The results showed that the design of the controller was reasonable and the load could be transferred quickly under the allowable range of electric reactor temperature [3]. When the load changes, the temperature and fuel efficiency of solid oxide fuel cell will change accordingly, leading to the fission of internal materials of battery and affecting its life. Therefore, R.Horalek and J.Hlava proposed a corresponding model predictive control scheme for this problem in 2015. This scheme not only predicted and controlled the battery temperature, fuel efficiency and oxygen efficiency, but also successfully limited the thermal change rate of the system and effectively prevented the battery damage [4]. In 2016, Tooran Emami and Alex Tsai applied robust PID controller to control the solid oxide fuel cell system with a power of 300KW. The performance of the system output under three different stability constraints was tested to prove the rationality of the controller design, and finally the effective operating range of solid oxide fuel cell parameters was given [5].

In China, Wang Lijin proposed a control strategy based on the distributed lumped parameters model of one-dimensional internal reforming solid oxide fuel cell in 2008, which mainly applied three independent PID controllers to control the temperature, power and fuel efficiency of the battery in parallel. The results showed that the established control system was correct and feasible, and could maintain the constant output of the system in the case of load variation [6]. In 2014, Liu Xin established the mathematical model of solid oxide fuel cell including two auxiliary components of internal reforming device and combustion chamber, and controlled the composition, temperature, pressure, concentration and flow rate of fuel gas by using the nonlinear model predictive control strategy, making the whole power generation system in the expected normal operation state [7]. In 2016, Yang Ji established the mechanism model of the solid oxide fuel cell based on the dynamic...
change of reaction gas. Then the slide-mode interference observer based on the superhelix algorithm was used to estimate and compensate the modeling errors and external uncertainties. Finally the slide-mode controller was used to control the output of the battery. The results showed that the slide-mode controller with slide-mode observer could effectively control the input of the reactive gas and ensure the constant of the output voltage [8]. In 2018, Li Xiao obtained the battery mechanism model based on the analysis of the power generation principle of solid oxide fuel cell, and then simulated the input and output data in the mechanism model by using the autoregressive sliding average model to obtain the battery identification model. Then the author designed a GPC algorithm based on the identification. The results showed that the output performance index of the battery had a good tracking effect when the load of the external circuit changed [9].

SOFC is a strongly nonlinear system with multiple inputs and outputs. In the design of the controller, there are certain requirements on the real-time, adaptive and robust of the whole system, so there are relatively few researches on SOFC control [10-13]. Since the research on control of SOFC is still in the initial stage, it has important theoretical value and practical significance for the design of its controller.

2. The principle of power generation for SOFC single battery

The power generation principle of SOFC single battery is that oxygen (O$_2$) in the air channel penetrates through the porous electrode to the cathode side, and the reduction reaction occurs to produce oxygen ions (O$^{2-}$). Oxygen ions reach the anode side through the electrolyte due to diffusion and oxidize with the hydrogen rich gas (H$_2$) in the fuel channel that enters the anode side through osmosis to form water and release electrons. Electrons form a closed loop through the external load to complete the external power supply behavior.

An adjustable parameter model of SOFC single battery is used in this paper. The model has a certain flexibility due to it contains two adjustable parameters that can be changed moderately according to the actual operating of the battery, so this paper continues to use this model for control research. Fig.1 shows the adjustable parameter model of SOFC single battery by Simulink, q1 is the hydrogen input molar flow, q3 is the water vapor input molar flow, U$_{cell}$ is the voltage of SOFC single battery, P$_{cell}$ is the power of SOFC single battery.

![Figure 1. Adjustable parameter model of SOFC single battery by Simulink.](image)

3. Introduction to genetic algorithm

In 1975, professor J.Holland of the University of Michigan first proposed the concept of genetic algorithm in his book *Adaptation in Natural and Artificial Systems*. Genetic algorithm is a heuristic search algorithm which simulates the natural selection of Darwin's biological evolution theory and the biological evolution process of genetic mechanism.

When genetic algorithm is applied to solve practical optimization problems, it is necessary to use certain coding form to encode each solution in the problem solution space. Each solution after coding
is called chromosome, and a certain number of chromosomes are randomly selected to form the initial population. The fitness of each chromosome is calculated according to the pre-set evaluation function, and the fitness of the better chromosome is larger. Then, according to the principle of "survival of the fittest", the chromosomes with greater fitness are selected with a certain probability for replication, crossover and mutation to produce a new generation of chromosomes and form a new population. Through the multiple evolution of limited number times, the offspring population will be more adapted to the environment, and the optimal individual in the last population after decoding will be the optimal solution or approximate optimal solution of the problem.

4. Design of genetic algorithm PID controller

British scholars Collender and Stevenson first proposed the concept of PID controller in 1936. PID controller is a series correction device composed of proportional, integral and differential units, which is mainly used to control industrial systems with basic linear and dynamic characteristics that do not change with time to achieve the desired operating state. Its working principle is that the error signal of the system forms the control signal after the action of certain control law, and then the control signal is used to control the output performance index of the controlled object. The time domain form of the PID controller can be expressed by the following formula.

\[ u(t) = K_P \times e(t) + K_I \times \int e(t)dt + K_D \times \frac{de(t)}{dt} \]  

(1)

Where, \( e(t) \) is the error signal; \( u(t) \) is the control signal; \( K_P, K_I(T), K_D(T_D) \) are the weighted values of the error signal and its integral and differential.

![Diagram](image_url)

**Figure 2.** Structure diagram of genetic algorithm PID control of SOFC single battery.

![Flow Chart](image_url)

**Figure 3.** Flow chart of genetic algorithm PID control of SOFC single battery.
The value of parameters $K_P$, $K_I$ and $K_D$ will directly affect the effect of PID controller, so it is very important to study the optimization tuning method of PID controller parameters. The optimization tuning method in the thermal system are mainly simple value method and expert tuning method, but the above methods have some defects in controlling SOFC single battery. The simple value method is sensitive to the initial value set by the system, which easily leads to the failure of optimization. Expert tuning method need to organize a large amount of expert empirical knowledge to form a special knowledge base, which consumes a lot of time and cannot guarantee the accuracy of empirical knowledge. The genetic algorithm can realize the PID controller parameter adaptive tuning and has the rapidity. Therefore, genetic algorithm is used to optimize the PID controller parameters within a reasonable range, and the optimal parameters $K_P$, $K_I$ and $K_D$ are used to control the output voltage of SOFC single battery. Fig.2 shows the structure diagram of controlling the output voltage of SOFC single battery by using the genetic algorithm PID controller, and Fig.3 shows the corresponding flow chart.

5. Experimental simulation and analysis

In the adjustable parameter model of SOFC single battery, when the water vapor input molar flow remains constant, there is an optimal hydrogen input molar flow to maximize the output voltage of SOFC single battery [14]. Therefore, in this paper, the water vapor input molar flow is set as 0.2mol/s, and then the hydrogen input molar flow is controlled by genetic algorithm PID controller, so that the output voltage of SOFC single battery can reach the user’s expected value of 0.85v.

The genetic algorithm used in this paper is realized by the genetic algorithm of MATLAB and the function of direct search toolbox. The coding form is real number coding, the initial population size is 50, the number of elite is 10, the ratio of cross offspring is 0.6, the maximum evolution algebra is 30, the selection function uses random consistent selection, the crossover function uses scatter crossover, and the mutation function uses constrained adaptive mutation. The whole system is operated under the above constraints. The variation of system error is shown in Fig.4, the variation of hydrogen input molar flow is shown in Fig.5, the variation of output voltage of SOFC single battery is shown in Fig.6, and the output power of SOFC single battery is shown in Fig.7.

As can be seen from Fig.4, when the running time increases from 0s to 0.59s, the system error decreases sharply. When the running time increases from 0.59s to 1.37s, the system error increases slowly. When the running time exceeds 1.37s, the system error is zero and no longer changes. It indicates that the control signal generated by the genetic algorithm PID controller can quickly and effectively control the system error to decrease, and that is to make the output voltage of SOFC single battery reach the expected value.

As can be seen from Fig.5, when the running time increases from 0s to 1.38s, the hydrogen input molar flow decreases significantly. When the running time exceeds 1.38s, the hydrogen input molar flow maintains at 1.33mol/s and does not change. Since the water vapor input molar flow has been set as 0.2mol/s in advance, and the hydrogen input molar flow is 1.33mol/s when the system is running.
stably. This indicates that the ideal ratio of hydrogen input molar flow to water vapor input molar flow during normal operation of SOFC single cell should be 6.65:1.

As can be seen from Fig.6, the output voltage of SOFC single battery reaches the maximum value of 0.854v at 0.63s, and the overshooting is 0.47%. After 1.19s, the output voltage of SOFC single battery remains at 0.85v, and the system has no steady-state error. It shows that the genetic algorithm PID controller can effectively control the output voltage of SOFC single battery to reach the user's expected value of 0.85v.

As can be seen from Fig.7, when the running time increases from 0s to 1.46s, the output power of SOFC single battery shows a downward trend. When the running time exceeds 1.46s, the output power of SOFC single battery is maintained at 1.92w. The output voltage and output power of SOFC single battery does not reach the constant value at the same time, and there is a small 0.09s delay, indicating that the hydrogen input molar flow will affect the internal current of the battery and the delay of this process is 0.09s.

6. Conclusions
In this paper, based on the input and output characteristics of SOFC single battery adjustable parameter model, a corresponding genetic algorithm PID controller is designed to control the output voltage of SOFC single battery. The following conclusions are obtained through simulation.

1) When the SOFC single battery is in normal operation, the ideal ratio of hydrogen input molar flow to water vapor input molar flow is 6.65:1.

2) The hydrogen input molar flow affects the internal current of SOFC single battery, and this process takes 0.09s.

3) The designed genetic algorithm PID controller can effectively control the hydrogen input molar flow to the optimal value, so that the output voltage of SOFC single battery can be maintained constant.

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References

[1] Eva Frey, SOFC Powering-The Telecommunication in Future, SIEMENS. 2005: 305-309.
[2] Maryam Sadeghi Reineh, Faryar Jabbari, Enhanced Power Generation in SOFC Using Artificial Limits on Actuator Control Signals, Journal of Electrochemical Energy Conversion and Storage. 2019, 16: 1-9.
[3] So-Ryeok Oh, Jing Sun, Model Predictive Control for Power and Thermal Management of Integrated Solid Oxide Fuel Cell and Turbocharge System, IEEE transactions on control systems technology. 2014, 22 (3): 911-920.
[4] R.Horalek, J.Hlava, Multiple Model Predictive Control of Grid Connected Solid Oxide Fuel Cell for Extending Cell Life Time, 2015 23rd Mediterranean Conference on Control and Automation (MED). 2015: 310-315.
[5] Tooran Emami, Alex Tsai, David Tucker, Robust PID controller design of a solid oxide fuel cell gas turbine, Proceeding of the ASME 2016 14th International Conference on Fuel Cell Science. 2016: 1-8.
[6] Wang Lijin, Zhang Huisheng, Wen Shilie, Control Strategy Research of Direct Internal Reforming Solid Oxide Fuel Cell, Proceedings of the CSEE. 2008, 128(20): 94-98.
[7] Liu Xin, Hao Xiaohong, Yang Xinhua, Nonlinear model predictive control of the direct internal reforming solid oxide fuel cell system, Chemical industry and engineering progress. 2014, 33(4): 900-906.
[8] Yang Ji, Dian Songyi, Pu Ming, Study on Performance of Sliding Mode Control of Solid Oxide Fuel Cells, Computer Simulation. 2016, 33(3): 99-104.
[9] Li Xiao, Li Junhong, Shen Wenbing, Modeling and generalized predictive control of solid oxide fuel cell, Battery Bimonthly. 2018, 48(6): 381-383.
[10] Matheus B. de O. e Silva, Jussara F.Fardin, Modeling and Grid Connection of Solid Oxide Fuel Cell (SOFC) based on P-Q Theory for Stationary Loads, 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM). 2015: 541-545.
[11] Wu Xiaolong, Xu Yuanwu, Hu Rong, Fault modeling and simulation comparative study of two solid oxide fuel cell system, Control Theory & Applications. 2019, 36(3): 408-412.
[12] Huo Haibo, Zhu Xinjian, Cao Guangyi, Research status and development of modeling and controlling for SOFC, Chinese Journal of Power Sources. 2017, 31(10): 833-835.
[13] Jipeng Gu, Caixia Wang, Modeling and Simulation of the Electrical Characteristic of Solid Oxide Fuel Cells, 2019 4th International Symposium on Computer and Information Processing Technology. Guizhou, China.
[14] Jipeng Gu, Caixia Wang, Particle Swarm PID Control of Solid Oxide Fuel Cell, 2019 The 2nd International Conference on Robotics, Control and Automation Engineering (RACE 2019). Lanzhou, China.