Simulation study on genetic algorithm control of hydrogen fuel cell gas supply system

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Abstract. Fuel cell as a new clean energy, its advantages of high efficiency, low emission and low noise have attracted the attention of domestic and foreign governments and scholars. To this end, based on the requirement analysis of the hydrogen fuel cell gas supply system, this paper focuses on the genetic algorithm optimization PID control strategy of the hydrogen fuel cell gas supply system. The simulation model is built on the Matlab/Simulink platform and compared with the conventional PID algorithm in the model. The simulation results show that the comprehensive index of PID control algorithm optimized by genetic algorithm is better than that of conventional PID algorithm, which proves the improvement effect of the proposed control strategy on the dynamic response of the gas supply system.

1. Introduction

Hydrogen is an ideal fuel for fuel cells, which has many advantages such as high specific power, fast start-up, high energy conversion efficiency and low environmental pollution. However, hydrogen fuel cells can cause 'hydrogen hunger', or fuel hunger, due to the delayed response of gas supply or the uneven distribution of current and voltage between different plates. Therefore, Pan Jungang et al. [1] studied the control effect of multi-mode PID (M-OID) and PID control method in the air transmission system of 140 kW high power vehicle proton exchange membrane fuel cell. It is concluded that the M-PID overshoot is small, and the oxygen starvation or oxygen saturation of fuel cell can be avoided by reducing the number of air quality jumps. In view of the characteristics that the position sensor cannot be installed in the two-stage pressurized fuel cell air compressor, Wang et al. [2] proposed the I/F starting combined with the improved sliding mode observer to achieve rapid start and high-speed stable operation. Aiming at the performance degradation of air compressor, Zhou Su et al. [3] added adaptive look-up table algorithm on the basis of feed-forward compensation decoupling closed-loop control algorithm, eliminated the integral saturation phenomenon of PI controller, and improved the flow control effect of inlet air. Li Mingjian et al. [4] built a dynamic simulation model of fuel cell air system on AMESim platform, and demonstrated the dynamic response of air flow, pressure, temperature and humidity in fuel cell under the condition of dynamic load change through experiments. The error between the simulation results and the actual working situation of fuel cell is controlled within 7 %. Similarly, Liu Dong'an et al. [5] simulated and analyzed the hydrogen supply circuit of fuel cell vehicle through AMESim platform, which focused on the detailed mathematical analysis of the necessary
components of hydrogen circuit such as hydrogen bottles. After experiments, all levels of pressure in hydrogen were controlled within 4.5% of the actual situation.

By analyzing the structure of the hydrogen fuel cell gas supply system, this paper puts forward the control requirements of the hydrogen fuel cell gas supply system, and focuses on the genetic algorithm optimization PID control strategy of the hydrogen fuel cell gas supply system.

2. Control requirements for gas supply control system of hydrogen fuel cell

Hydrogen fuel cell gas supply system is a complex nonlinear system including temperature, humidity and mass. The gas supply system includes hydrogen supply system and air supply system. The positive extreme hydrogen supply is provided by the hydrogen tank, and the hydrogen tank is controlled by the electromagnetic valve. Compared with the negative extreme, the control of the air compressor is a transient process. Therefore, when analyzing and controlling the gas supply system, only the cathode is modeled and controlled, and the positive extreme gas supply pressure, that is, the hydrogen pressure can be directly the same as the negative extreme. According to the modeling method in Reference [6], the control parameters are proposed as shown in Table 1.

| Meaning                              | Numbers and units          |
|--------------------------------------|----------------------------|
| Working temperature T                | 353K                       |
| Air molar mass $M$                   | $29 \times 10^{-3}$ kg/mol |
| Oxygen molar mass $M_{O_2}$         | $32 \times 10^{-3}$ kg/mol |
| Hydrogen mole mass $M_{H_2}$        | $2 \times 10^{-3}$ kg/mol  |
| Nitrogen molar mass $M_{N_2}$       | $28 \times 10^{-3}$ kg/mol |
| Cathode outlet flow coefficient $k_{ca, out}$ | $1.28 \times 10^{-6}$ mol/(s·pa) |
| Outlet pressure $P_b$               | 1.01xbar                   |
| Heat ratio coefficient $\gamma$     | 1.4                        |

Based on the material conservation theorem and the state equation of ideal gas, the gas dynamics of hydrogen fuel cell stack cathode can be described by the following equations:

$$\dot{P}_{ca} = \frac{RT_{ca}}{M_{a,ca}V_{in}}(W_{ca, in} - W_{con})$$  \hspace{1cm} (1)

In the formula, $T_{ca}$ represents the temperature of the stack cathode, $M_{a,ca}$ represents the average molar mass of gas in the stack cathode, $W_{con}$ represents the rate of oxygen consumption in the stack, which can be calculated by combining the stack current and the material conservation equation:

$$W_{con} = \frac{nI_{st}M_{O_2}}{4F}$$  \hspace{1cm} (2)

In the formula, $n$ denotes the number of stack cells, $I_{st}$ denotes the current value of stack output, $F$ denotes Faraday constant, $M_{O_2}$ denotes the molar mass of oxygen.

In the process of fuel cell operation, it is necessary to prevent the phenomenon of 'hypoxia' and 'excess oxygen' of fuel cell. The oxygen flow provided by the gas supply system must be greater than that required by the electrochemical reaction, so that the reactant supply will not be insufficient. The air supply system needs to provide enough air flow but not unlimited increase. Air compressors also need
to consume energy to provide air. The useless consumption of air compressors will also reduce the efficiency of the system and cause 'oxygen saturation'.

3. Controller design of hydrogen fuel cell gas supply control system

According to the analysis of the References [7] and [8], the conventional PID control cannot satisfy the real-time adjustment of gas pressure similar to that in the case of external interference. Therefore, this paper intends to add genetic algorithm to optimize the design of the hydrogen fuel cell gas supply system.

3.1. Genetic algorithm design method

Figure 1 shows the schematic diagram of the PID controller structure optimized by genetic algorithm, where $y(t)$ is the output gas pressure value and $R(t)$ is the given gas pressure value, where $e(t)$ is the deviation between the actual pressure value and the target pressure value is collected, and $G(s)$ is the genetic algorithm to optimize the PID controller.

![Figure 1. Optimization of PID controller structure by genetic algorithm.]

3.2. Parameter determination of genetic algorithm

3.2.1. Selection of fitness function and determination of input parameters. According to the working principle and composition of the hydrogen fuel cell gas supply system, this paper the boundary construction method to design the fitness function of genetic algorithm:

$$\text{val}(F(x)) = \begin{cases} C - \int_0^{t_f} [w_1 |e(t)| + w_2 u^2(t) + w_3 \sigma] dt + w_4 t_s, & F(x) < C \\ 0, & \text{others} \end{cases}$$

In the formula, $C$ is the maximum estimate of the objective function $F(x)$, $t_f$ is the rise time, $e(t)$ is the system deviation, $u(t)$ is the controller output, $w_1$, $w_2$, $w_3$, $w_4$ is the proportional coefficient, $w_1 + w_2 = 1$, $w_1 + w_3 >> 1$, $w_1 >> w_4$. The maximum value of the objective function determined in this paper is $C=125$, and the determined proportional coefficient is $w_1 = 0.99$, $w_2 = 0.01$, $w_3 = 100$, $w_4 = 0.001$.

In order to obtain the PID parameters with the best fitness, the upper and lower limits of the input parameters of the controller are selected by theoretical calculation combined with the actual engineering tuning method of hydrogen fuel cell. The preliminary PID parameters are proportional coefficient $K_p = 0.090$, integral coefficient $K_i = 535$ and differential coefficient $K_d = 0$. 
Based on the above parameter results, after repeated debugging of simulation experiments, the lower and upper limits of the three decision variables are $K_p \in [0.02, 0.1]$, $K_i \in [100, 1000]$, $K_d \in [0, 0.006]$ respectively.

3.2.2. Coding method and initial population setting. In this paper, the real number encoding is used in the PID parameter timing, and the initial population number is set to $N=100$. The value is generated by the computer according to the actual situation of the control object, and the maximum genetic algebra $\text{Maxgen} = 100$ is selected. The genetic algorithm iterative curve of the system is shown in Figure 2.

![Fitness function value](image)

**Figure 2.** The iterative curve of genetic algorithm.

It can be seen from Figure 2 that when the 100th generation is about, the fitness function value can converge well, so it is appropriate to select the maximum genetic algebra as 100.

3.2.3. Genetic operator design. According to the control requirements of the hydrogen fuel cell gas supply system, this paper selects the roulette wheel method as the selection function, and the specific operation is as follows: the fitness $f(i=1, 2, ..., M)$ of each individual in the group is calculated, and $M$ is the group size. Calculate the probability of individuals in each generation being inherited to the next generation and the cumulative probability of each individual:

$$P(x_i) = \frac{f(x_i)}{\sum_{j=1}^{N} f(x_j)} \quad (4)$$

$$q_i = \sum_{j=1}^{i} P(x_j) \quad (5)$$

In the formula, $q_i$ is called the accumulation probability of chromosome $x_i$ ($i=1, 2, ..., n$); a uniformly distributed pseudo-random number $r$ is generated in the interval $[0, 1]$; If $r < q_i$, select individual 1; Otherwise, select individual $k$ such that: $q_{k-1} < r \leq q_k$ holds; Repeat the above steps until the maximum genetic algebra is reached.

Because the real number coding is used in this paper, the most simple and convenient arithmetic crossover method is used as the crossover function, arithmetic crossover refers to the linear combination of two individuals to produce two new individuals. Suppose that the parent individual is $\text{pop}_1$ and $\text{pop}_2$, then the crossed offspring individual is:

$$\begin{align*}
\text{pop}_{1}^{*+1} &= \alpha \cdot \text{pop}_1 + (1 - \alpha) \cdot \text{pop}_2 \\
\text{pop}_{2}^{*+1} &= (1 - \alpha) \cdot \text{pop}_1 + \alpha \cdot \text{pop}_2
\end{align*} \quad (6)$$
In the formula, \( t \) is the current algebra, \( \alpha \) is a proportional factor, its value is randomly generated between \((0,1)\), \( pop_{t+1} \), \( pop_{t+1} \) is a cross-generation individual. The variation mode is Gaussian variation. This is described in Reference [9].

4. Analysis of simulation experiment

According to the mathematical model of hydrogen fuel cell gas supply system proposed in [10], the Simulink module in Matlab is used to build the simulation model of the conventional PID control algorithm and the genetic algorithm is used to optimize the parameters of PID. Under the condition of current step input, the simulation results of the two algorithms are analyzed and compared. The simulation model of conventional PID control and genetic algorithm optimization PID parameter control is shown in Figure 3, and the simulation results are shown in Figure 4.

**Figure 3.** Conventional PID control simulation model and PID parameter control simulation model optimized by genetic algorithm.

**Figure 4.** Simulation results of two control algorithms.

It can be seen from Figure 4 that the gas pressure starts from the initial value 0 and reaches the set steady-state value of 1 bar after about 18s. At the same time, the rise time and the adjustment time are also greatly improved than the traditional PID. From the perspective of overshoot, the overshoot of PID controller optimized by genetic algorithm is basically not, while the overshoot of conventional PID curve is 10%. Based on the comparison of the above time-domain performance indexes, the comprehensive index of the genetic algorithm with PID control is better than that of the conventional PID algorithm, which proves the superiority of the proposed control strategy.

5. Conclusions

In this paper, the control requirements of hydrogen fuel cell are analyzed, and the control strategy of PID control optimized by genetic algorithm is proposed. The fitness function is selected and the range of input parameters is determined according to the selected fitness function. After determining the
parameter encoding and the setting of the initial population, the genetic operation design including selection, crossover and mutation is completed, and the simulation verification is carried out in Matlab/Simulink. The experimental results show that the comprehensive index of genetic algorithm with PID control is better than that of conventional PID algorithm, which proves the superiority of the proposed control strategy.

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