A double closed loop control algorithm based on current mode in full bridge circuit

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Abstract. In order to improve the problems of large output current and voltage ripples and slow system response when the full-bridge circuit is working. This paper proposes a double closed-loop control algorithm based on current mode. Use fuzzy controller to optimize the parameters of voltage outer loop PID controller. The genetic controller is used to optimize the parameters of the current inner loop PID controller. After the dual closed-loop structure of the current control mode is optimized for the traditional PID controller, the overshoot is reduced, the system response speed is accelerated and the current ripple and voltage ripple are also greatly reduced. The simulation verifies the effectiveness of the designed double closed-loop control algorithm.

1. Introduction

With the continuous increase in the number of vehicles, due to the consumption of oil by traditional fuel vehicles, China has begun to vigorously promote the development of new energy vehicles [1]. At present, common new energy vehicles include hybrid electric vehicles and pure electric vehicles [2]. Since pure electric vehicles do not produce exhaust gas during driving and have little environmental pollution, pure electric vehicle technology has been rapidly developed [3]. Since hydrogen fuel cell vehicles only produce water and heat during driving [4] and no other polluting gases are generated, hydrogen fuel cell vehicles have become a hot spot in the field of pure electric vehicle research [5].

The control algorithms for full-bridge circuits mainly include voltage-based and current-based control algorithms [6]. Due to the current mode-based control method of the full-bridge circuit, the system has a fast response speed [7]. At present, double closed-loop control based on current mode is widely used in the control of full-bridge circuits [8]. However, if the traditional PID controller is selected in the double closed-loop control system, the control effect may not be optimal [9]. At present, intelligent algorithms are generally used to modify the parameters of traditional PID controllers [10]. At present, the commonly used intelligent algorithms include fuzzy control, neural network, expert control and genetic algorithm.

In this paper, the double closed-loop control algorithm based on the current mode is selected as the control algorithm of the full-bridge circuit. And use fuzzy control algorithm and genetic control algorithm to modify the traditional PID controller.
2. Double closed loop control structure based on current mode

The topology of the full-bridge circuit is shown in Figure 1.

In Figure 1, the full bridge circuit mainly includes the primary side circuit and the secondary side circuit. The primary side circuit is an H-bridge circuit composed of 4 power tubes and 4 diodes. The secondary circuit is a half-wave rectifier circuit composed of diodes D5 and D6, reactor L1 and capacitor C1.

The double closed-loop structure of the current control mode can speed up the adjustment speed of the system and reduce the output voltage and current ripple of the system. Therefore, this paper selects the double closed-loop control algorithm based on current mode to realize the real-time control of the full-bridge circuit.

Because the traditional PID will slow down the system response speed and the output voltage and current ripple are large. For this reason, this paper chooses fuzzy control algorithm to optimize the voltage outer loop PID control and genetic algorithm optimizes the current inner loop PID controller. The dual closed-loop control block diagram based on current mode is shown in Figure 2.

2.1. Design of fuzzy PID controller

Fuzzy control has the advantages of simple method, convenient calculation, can accurately and effectively avoid data interference, capture the main information of data, effectively reduce the difficulty of processing system input and processing, and can effectively control the system to achieve what we expect effect.
The fuzzy controller designed in this paper has 3 output variables and 2 input variables. The function of the 3 output variables is to modify the parameters of the voltage outer loop PID controller in real time. Its output value is set to $\Delta K_P$, $\Delta K_I$, $\Delta K_D$. The two input variables are the rate of change of the output voltage of the full-bridge circuit and the given voltage deviation $e_u$ and the voltage deviation $e_{uc}$ of the full-bridge circuit. The basic domain of voltage deviation is selected as [-6, 6] and the quantized domain is selected as [-8, 8]. The basic domain of the change rate of voltage deviation is selected as [-2, 2], and the quantized domain is selected as [-8, 8].

Select the fuzzy domain of the output voltage $u_{out}$ of the DC/DC conversion module as {-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6}. The basic domain of voltage deviation $e_u$ is selected as [-6, 6] and the quantized domain is selected as [-8, 8]. The basic domain of the change rate $e_{uc}$ of voltage deviation is selected as [-2, 2] and the quantized domain is selected as [-8, 8]. The fuzzy domains of output $\Delta K_P$, $\Delta K_I$, $\Delta K_D$ are selected as [-3, 3] and the basic domains are [-0.6, 0.6] and [-0.1, 0.1] and [-2, 2] respectively. The scale factors are selected as 0.2, 1/30 and 2/3.

Table 1 is the fuzzy control rule table of parameters $\Delta K_P$, $\Delta K_I$, $\Delta K_D$.

| $\Delta K_p$ | $e_u$ | $e_{uc}$ |
|-------------|--------|---------|
| NB | PB | PB | PM | PM | PS | ZO | ZO |
| NM | PB | PB | PM | PS | ZO | NS | NS |
| PS | PM | PM | PS | ZO | NS | NS | NS |
| PM | PS | ZO | NS | NM | NM | NM | NB |
| PB | ZO | ZO | NS | NM | NM | NB | NB |

| $\Delta K_i$ | $e_u$ | $e_{uc}$ |
|-------------|--------|---------|
| NB | NB | NB | NM | NB | NS | ZO | ZO |
| NM | NB | NB | NM | NS | ZO | NS | ZO |
| NS | NB | NM | NS | NS | ZO | PS | PS |
| PS | NM | NM | NS | ZO | PS | PM | PM |
| PM | ZO | ZO | PS | PS | PM | PB | PB |
| PB | ZO | ZO | PS | PM | PB | PB | PB |

| $\Delta K_d$ | $e_u$ | $e_{uc}$ |
|-------------|--------|---------|
| NB | PS | NS | NB | NB | NM | NM | PB |
| NM | PS | NS | NB | NM | NM | NS | ZO |
| NS | ZO | NS | NM | NM | NS | NS | ZO |
| PS | ZO | NS | NS | NS | NS | NS | ZO |
| PM | PB | PS | PS | PS | PS | PS | PS |
| PB | PB | PM | PM | PM | PM | PM | PB |

2.2. Design of genetic PID controller

Fitness is an index to evaluate the pros and cons of individuals. The value of fitness will affect the selection process of subsequent optimization links. Therefore, it is very necessary to design a good and
suitable fitness function. The fitness function must be continuous and single-valued. When selecting the fitness function, the calculation should be simplified as much as possible, so that similar problems can be handled well. The parameter variables in the fitness function selected in this paper include the input current deviation value, the modulation signal value and the output current value. The fitness function selected in this paper is shown in Equation (1).

The fitness function is:

\[
\text{val}(F(x)) = \begin{cases} 
C - \int_0^t (w_1 e_i(t) + w_2 d_s(t) + w_3 i_{Li}(t)) dt, & F(x) < C \\
0, & \text{others}
\end{cases}
\]  

(1)

In the formula, \( C \) is the maximum estimated value of the objective function \( F(x) \), \( e_i(t) \) is the input current deviation value of the full-bridge circuit, \( d_s(t) \) is the modulation signal value of the full bridge circuit. \( i_{Li}(t) \) is the output current value of the full bridge circuit. \( w_1, w_2, w_3 \) are the proportional coefficients, \( w_1 + w_2 + w_3 = 1 \). After calculation, the maximum value of \( F(x) \) \( C = 230 \). The determined scale factor is \( w_1 = 0.42, w_2 = 0.21, w_3 = 0.37 \).

The rest parameter design of the genetic PID controller is shown in the parameter Table 2 of the genetic PID controller.

| Parameter                | Set value |
|--------------------------|-----------|
| Population size          | 100       |
| Maximum genetic algebra  | 120       |
| Crossover probability    | 0.1       |
| Mutation probability     | 0.01      |

3. Simulation analysis of double closed loop control algorithm

Use MATLAB simulation tools to build a full-bridge circuit simulation model to verify the simulation performance of the designed control algorithm. Figure 3 shows the simulation result of the intelligent algorithm optimization without using the intelligent algorithm. Figure 4 shows the simulation result of the intelligent algorithm optimization.

![Figure 3. Diagram of simulation results without using intelligent algorithms to optimize.](image-url)
According to Figure 3 and Figure 4, the output current performance index comparison is shown in Table 3, and the output voltage performance comparison table is shown in Table 4.

Table 3. Comparison table of output current performance indicators.

| Performance         | Simulation HM11 | Simulation HM12 |
|---------------------|-----------------|-----------------|
| Overshoot           | 14.29%          | 8.45%           |
| Adjustment time     | 0.002s          | 0.0012s         |
| Peak time           | 0.00068s        | 0.00029s        |
| Current ripple      | 0.75A           | 0.1A            |
| Current ripple rate | 5.25%           | 0.71%           |

Table 4. Output voltage performance comparison table.

| Performance         | Simulation HM11 | Simulation HM12 |
|---------------------|-----------------|-----------------|
| Overshoot           | 14.28%          | 7.14%           |
| Adjustment time     | 0.002s          | 0.0018s         |
| Peak time           | 0.00067s        | 0.00057s        |
| Current ripple      | 3V              | 1.5V            |
| Current ripple rate | 0.86%           | 0.43%           |

From the analysis in Table 3 and Table 4, it can be concluded that after using fuzzy control and genetic algorithm to optimize the traditional PID controller, the system response speed is accelerated, the overshoot is reduced, the current ripple and voltage are reduced, and the expected effect is achieved. Verification The feasibility of the plan.

4. Conclusions
The double closed-loop control algorithm based on current mode proposed in this paper uses a fuzzy controller to optimize the parameters of the voltage outer loop PID controller and a genetic controller to optimize the parameters of the current inner loop PID controller. After the dual closed-loop
structure of the current control mode is optimized for the traditional PID controller, the overshoot is reduced, the system response speed is accelerated, and the current ripple and voltage ripple are also greatly reduced, achieving the desired effect.

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