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Research on DC Electronic Load System Based on PSO-PID Algorithm

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Abstract

At present, the control part of the DC electronic load is mainly based on analog control, that is, the control loop is controlled by an operational amplifier. Therefore, it is easy to cause slow response speed and overshoot in the process of current rise, and the improvement of response speed is of great significance to the test link. Therefore, this paper studies the digital control of DC electronic load. The DC electronic load control system has the characteristics of nonlinearity, and it is difficult to complete the theoretical modeling. Therefore, the MATLAB system identification toolbox is used to obtain the mathematical model. The traditional PID tuning method has a long time and poor effect. This paper adopts a parameter self-tuning PID controller based on particle swarm optimization algorithm. Through MATLAB simulation, the traditional PID control and particle swarm optimization PID control are simulated and compared. The results show that the digital controller has faster response speed and smaller overshoot than the conventional controller, and the system performance is significantly improved.

Keywords: DC electronic load, PID control, particle swarm optimization, overshoot, the dynamic response

1. Introduction

When the power supply leaves the factory, discharge test should be carried out, and the traditional static load cannot meet the test demand (Liang, J. & Mu, P., 2018). DC electronic load is a kind of instrument that simulates the traditional static load (Zhang, W., Yao, T., Zhao, J. & et al., 2015) and absorbs and converts the electric energy into other forms of energy storage or consumption, which has a wide range of uses in power supply and battery performance testing. The electronic load can be controlled by computer to maintain high accuracy according to the needs of actual testing, which overcomes the influence of environmental factors on the general load to a large extent, so as to ensure the accuracy of testing. The DC electronic load studied in this paper is through MOSFET to consume energy so as to achieve the function of simulating the actual load. According to the different applications, the DC electronic load can work in four modes: constant current mode, constant voltage mode, constant resistance mode and constant power mode. The constant current mode absorbs the electrical energy provided by the power supply at a constant current value, but its dynamic response is insufficient when some equipment needs high current testing. With the emergence of intelligent algorithms such as neural networks, the digital control of instruments becomes more excellent and flexible. Some scholars have studied PID-based program control of electronic load (He, S., Kong, F., & Yang, L., 2012). The key point of PID control is parameter setting, while traditional methods such as Ziegler-Nichols method and trial and error method are very uncertain and difficult to get good parameters (Meng, J., Chen, Q., & Zhang, K., 2013). In 1995, Dr. Eberhart and Dr. Kennedy proposed an evolutionary computation method based on swarm intelligence theory: particle swarm optimization algorithm (Kennedy J & Eberhart R., 1995). The PSO algorithm has fast convergence speed and is easy to implement. Therefore, aiming at the disadvantage of slow dynamic response of DC electronic load, the PSO algorithm is proposed to optimize PID parameters, and the fitness function of PSO algorithm is established with two indexes of dynamic response speed and overshoot. The effectiveness of PSO algorithm is verified by simulation.

2. DC Electronic Load Power Circuit Partial Model Establishment

DC electronic load mainly depends on MOSFET for energy consumption, MOSFET work in the constant current region (also known as saturation region, amplification region, active region). In this region, when the voltage at both ends of the gate and source is constant, the current almost does not change with the voltage at both ends of the drain and source, showing a constant current characteristic. DC electronic load power circuit is mainly composed of operational amplifier and MOSFET closed loop, through sampling resistance to calculate the current value. Because the system composed of the circuit has nonlinear characteristics, it is difficult to complete the theoretical modeling, so the MATLAB system identification toolbox is used to identify the mathematical model of the system. This system is single input and single output, as shown in Figure 1 after data import, where the input of *mydata* is the reference voltage and the output is the current value of the load under test. Then select Transfer Function Models and enter 1 pole and 0 zeros in the options box. As shown in Figure 2, the curve fitting degree of the output waveform reaches 87.03%, and the obtained transfer function meets the requirements of system identification.

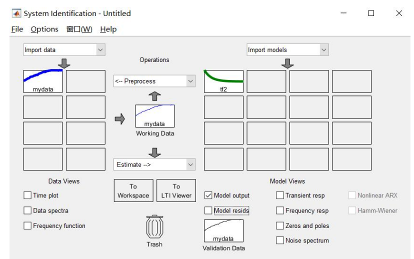

Figure 1. System identification toolbox interface

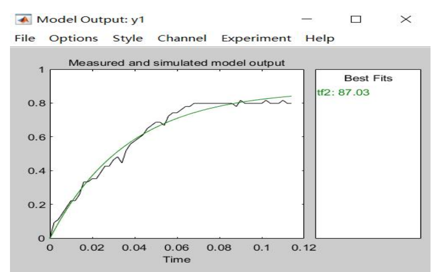

Figure 2. Fitting curve

Therefore, the approximate transfer function of DC electronic load system can be obtained by MATLAB system identification tool as follows:

$$G(s) = \frac{80.55}{s + 27.5} \tag{1}$$

3. The Control Method of DC Electronic Load

3.1. PID Control

Traditional PID control is widely used in industrial control and is a mature control method (Ang K H, Chong G & Li Y., 2005; Tian, Y., Xu, Y., Ren, K. & et al., 2020). Because the computer is a kind of sampling control, the control quantity can only be calculated according to the deviation value of sampling time. Therefore, the continuous PID control algorithm can not be directly used, need to adopt the discretization method. According to the continuous PID control algorithm, the discrete PID represents the continuous time t by a series of sampling time points, and replaces the integral by the error accumulation approximation, and the differential by the difference approximation. The discretization formula is as follows:

$$\begin{cases} u(k) = K_P e(k) + K_I \sum_{i=0}^{k} e(i) + K_D \left[e(k) - e(k-1) \right] \\ e(k) = r(k) - y(k) \end{cases} \tag{2}$$

Where, K_p is the proportion coefficient; K_i is the integral coefficient; K_d is the differential coefficient; $e(k)$ is the process error; $r(k)$ is the set value; $y(k)$ is the system output.

3.2. Particle Swarm Optimization PID Control

Particle swarm optimization (PSO) is a swarm intelligence algorithm with few parameters, simple and easy to implement. In the particle swarm optimization algorithm, three parameters of speed, position and fitness value are used to achieve the control of the target (Yang, X. & Wang, G., 2019). Formula (4) is the velocity of the updated particle, and formula (5) is the position of the updated particle.

$$v_{id}^{k+1} = w(k) v_{id}^{k} + c_1 r_1 (p_{id}^{k} - x_{id}^{k}) + c_2 r_2 (g_{id}^{k} - x_{id}^{k}) \tag{4}$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1} \cdot dt \tag{5}$$

Where, d is the dimension of the particle, and v_{id}^{k} is the current velocity of the k generation particle i; v_{id}^{k+1} is the current velocity of particle i of the k+1 generation; $w(k)$ is the inertia weight coefficient; c_1 and c_2 are the learning factors in the iterative updating process of particles; r_1 and r_2 are random numbers between [0,1]; p_{id}^{k} is the local optimal position; g_{id}^{k} is the global optimal position; x_{id}^{k+1} is the position of particle i of the k+1 generation; x_{id}^{k} is the position of particle i of the k generation. dt is the simulation displacement interval, and the PID control flow chart of particle swarm optimization is shown in Figure 3.

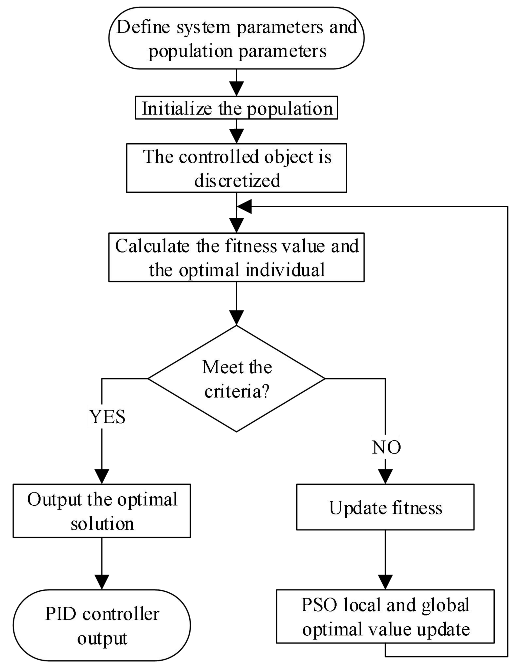

Figure 3. Particle swarm optimization PID control algorithm flow

3.3. Improvement of Particle Swarm Optimization Algorithm

In the iterative process of the basic particle swarm optimization algorithm, the particles are easy to be in the local extremum, which will affect the experimental results. This is due to the particle inertia velocity is too large, will lead to a long time can not get the optimal solution. Therefore, we can linearly reduce the inertia factor of the algorithm with the increase of the number of iterations, and its expression is:

$$w(k+1) = w(k) - 0.7 \frac{i}{n} w(k) \tag{6}$$

Where: i is the current iteration algebra, n is the total algebra.

3.4. Fitness Function Selection

The time-multiplied absolute error criterion (*ITAE*) is taken as the fitness function of the improved particle swarm optimization algorithm in this paper. The system designed by this criterion has the advantages of adjusting time period and small oscillation, and its performance indexes are as follows:

$$J(ITAE) = \int_0^{\infty} t \left| e(t) \right| dt \tag{7}$$

With the increase of the number of iterations, the smaller the value of J (*ITAE*), the better. The schematic diagram of improved PSO-PID control is shown in Figure 4.

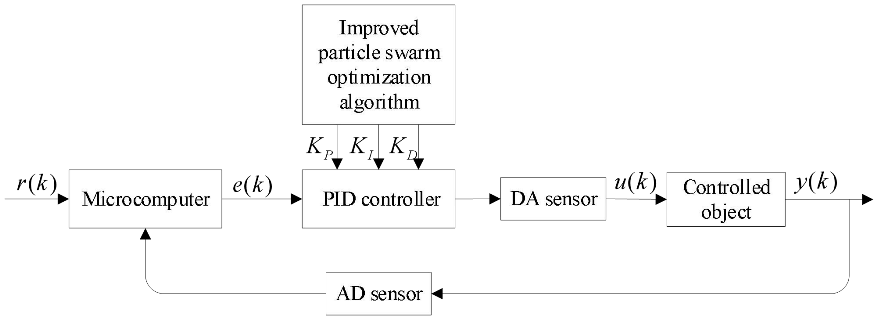

Figure 4. Schematic diagram of PID parameter optimization system

4. Experimental Study

4.1 Simulation Condition Setting

The output range of PID output $u(k)$ is set as [0,3], the simulation sampling period is set as 0.001 seconds, the simulation displacement interval dt is 0.3, the control period is 0.002 seconds, the inertia factors w, c1, c2 are 2, 2, 2, respectively, the initial velocity of the particle is 0, the speed limit is 1, and the position limit is [0,50]. The number of iterations is 20 and the population size is 20.

4.2 Analysis of Simulation Results

As shown in Figure 5, the parameters of the PID controller of the particle group algorithm are optimized for the k_p= 27.3792, k_i= 8.2902, k_d= 0, and the traditional PID is the k_p= 5.3084, k_i= 2.654, k_d= 0.0027.

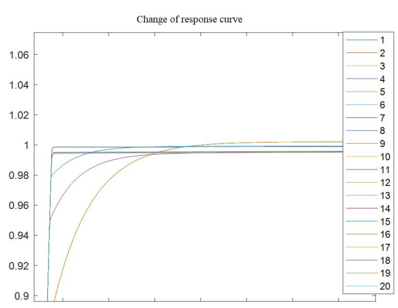

Figure 5. Response curve changes with iteration times

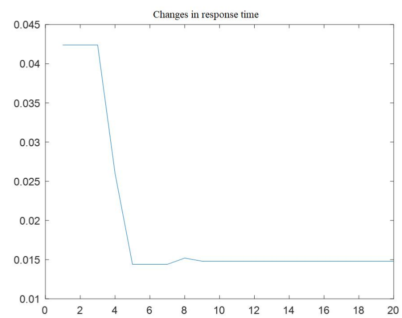

Figure 6. Transient response velocity curve

As shown in Figure 6 and Figure 7, the response speed tends to be stable at the 9th iteration, and the excess adjustment is minimized in the fourth iteration. As shown in Figure 8, the performance indicator *ITAE* is decreasing, and the control parameters are constantly approaching the optimal solution.

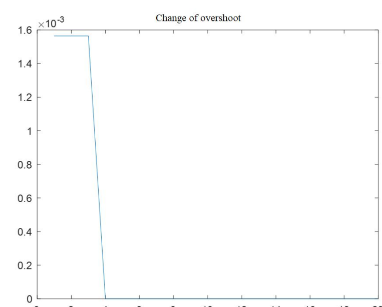

Figure 7. Changes curve of hypermodulation

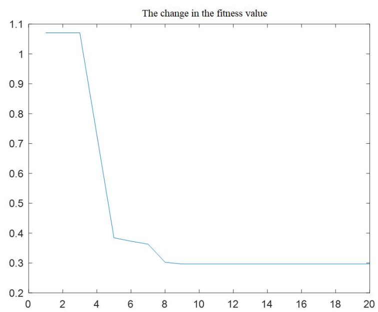

Figure 8. Shows the change curve of ITAE

As shown in Figure 9, compared with the traditional PID control, the PSO optimized system significantly accelerates the convergence speed, and its transient response time is only 0.0148s, while the traditional PID control takes longer to reach the stable state. According to the above simulation results, the improved PSO-PID algorithm can effectively improve the response speed of DC electronic load.

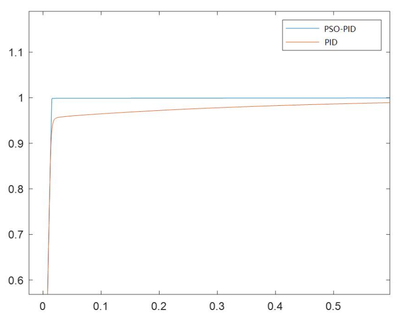

Figure 9. Response curve comparison

5. Conclusion

Dynamic response is an important index of electronic load in load test. From the simulation results, compared with the traditional PID control algorithm, it can be seen that the PID controller optimized by particle swarm optimization can achieve better control effect and accelerate the response speed of the system. In this paper, the electronic load system is controlled based on the ideal situation, but in addition to the input reference voltage, other factors such as noise interference will also affect the output performance. Therefore, the future research direction needs the control system to be able to deal with the interference in real time and minimize these effects. At the same time, it is necessary to consider a variety of influencing factors for multivariable control to be more suitable for the actual use of the situation, in order to reduce the impact of external factors on the dynamic response speed of electronic load, so that the research has more application value.

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