Improved genetic algorithm applied to model identification of typical thermal process of gas-steam combined cycle unit

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Abstract. The gas-steam combined cycle unit has high thermal efficiency, low pollution to the natural environment, and high cost performance. It has become the first choice in the sustainable development planning of the power industry, especially for the steel companies. It is of great practical value to establish the mathematical model of the combined cycle unit, especially the thermal process model. However, due to the influence of multi-parameters and non-linear correlation in a typical combined cycle unit, this paper uses an improved genetic algorithm to identify four typical thermal process models. The simulation results show that it is highly consistent with the measured results and is consistent with the traditional genetic algorithm. In contrast, there is also a significant improvement in fitting accuracy, which proves the feasibility and effectiveness of the improved algorithm in this paper in the identification of typical thermal process models of combined units.

1. Introduction

With the development of electric power industry and the improvement of environmental protection awareness, coal-fired generating units are in urgent need of being replaced. At present, gas-steam combined cycle unit is a kind of clean power generation system equipment with high power generation efficiency, little environmental impact, stability and extremely economic benefits. Since the 1980s, it has attracted much attention and is regarded as an important support for the power generation industry, as well as a hot research in the development of electric power at home and abroad. In order to design a better control strategy for combined cycle units, it is necessary to deeply analyze their performance and explore the typical process identification of gas-steam combined cycle units. In 2002, Gao Yang established a combined cycle gas turbine dynamic model and simulated the off-line working mode[1]. Then in 2009, Gao Lin, Xia Junrong and Dai Yiping proposed a new mathematical model of the combined cycle unit on this basis, and further proposed a matching method for the parameter identification of the model [2]. In the following year, Gao Lin et al. continued to propose the model and parameter identification matrix based on genetic algorithm [3]. Since 2010, more and more
scholars have also deeply studied the parameter identification of the combined unit model, such as genetic algorithm, neural network and cloud algorithm, in order to achieve system status monitoring and fault diagnosis[4-5]. Therefore, the combination of traditional genetic algorithm and other intelligent algorithms, as a new improvement direction, can improve the growth characteristics and priority link characteristics of genetic algorithm to a certain extent, making it more close to the real population structure.

2. Principle

The idea of genetic algorithm is from the target population, through multiple generations of gene coding changes, based on the principle of survival of the fittest, the evolution of individual populations to generate the optimal offspring. The genetic algorithm is essentially to find an approximate optimal solution to the problem. It is relatively simple and stable in structure, and has universality. But there are also some defects at the same time. In the case of a large sample size, the algorithm convergence speed is slow, and at the same time, it is easy to fall into the extreme value during the convergence process, resulting in early termination.

The core operation of the traditional genetic algorithm is 4 steps: generating initial population, selecting high-quality individuals, crossing fitness, and individual mutation. In the population structure, a full interaction structure is generally adopted, that is, all individual information of the entire population is shared. Selecting fitness is a key step in the inheritance of high-quality individual information, which can affect the efficiency of improving the quality of the entire population. Crossovers and mutations are the process of generating new individuals. Therefore, in order to improve the genetic algorithm, the selection strategy needs to be modified to speed up the optimization of the entire population and accelerate the iterative process.

This paper proposes an improvement idea. After the individual produces mutation, increase the population and network size, recalculate the genetic inheritance ratio, and make a second judgment on the evolution iteration. In order to increase the convergence rate, the relatively small of the two is adopted as the new generation to enter the next round of evolution. which is:

$$\prod \alpha = \frac{F_i \cdot k_i}{\sum F_j \cdot k_j}$$

$$\prod \beta = \frac{k_i}{k_1 + k_2 + k_3 + \cdots + k_n}$$

$$\prod \gamma = \min \{\prod \alpha, \prod \beta\}$$

Where, i, j represents the degree of variation of each genetic node, F represents the individual's fitness. Through the second judgment and iterative correction, the algorithm can reduce the number of iterations and make small-scale corrections to the optimized individual offspring. This can ensure that the calculation process is reduced and the convergence efficiency is improved without affecting the iteration direction. The flow chart of the improved algorithm is shown in Figure 1.
3. Results and discussion

Zhang Tianyang divided the typical thermal process identification problems of combined cycle units into three aspects: gas turbine fuel supply and combustion process, gas turbine work process, and waste heat boiler generating steam to promote steam turbine work process. After the gas turbine runs stably, the thermal process control of the control signal Vce only receives the influence of the speed signal N, the power signal P and the temperature signal t. The relationship between the fuel supply system and the fuel quantity signal can be simplified into a linear relationship, and most of the control influencing factors of waste heat boilers and steam turbines are complex nonlinear relationships. Therefore, the power generation process of the gas-steam combined cycle unit can be divided into four typical thermal processes: 1. The process of high temperature and high pressure air flow generated by fuel combustion; 2. The process of combustion efficiency and exhaust flow change; 3. The process of turbine and gas turbine power change; 4. The exhaust gas temperature of the waste heat boiler and the steam turbine power change process.

A typical combined cycle unit mathematical model requires more parameters, and many key signals are often not directly obtained by measurement. Therefore, after adopting the principle of equivalent conversion, the mathematical model of the relative change of combined cycle units is generally adopted. When designing the genetic algorithm network, only the rotation speed disturbance, exhaust temperature disturbance, fuel valve opening, gas turbine power, steam turbine power, gas turbine exhaust temperature, inlet guide vane opening and rotation speed of the compressor can be selected for pattern recognition.

Carry out parameter test simulation experiment for a 400MW combined cycle unit. Based on the variation of gas turbine power, oil valve opening degree, steam turbine power, and gas turbine outlet
temperature, the simulation results are compared with the measured data (see figure 2, figure 3, figure 4 and figure 5).

![Graph 1](image1.png)

**Figure 2.** Comparison between the variation of gas turbine power and its simulation.

![Graph 2](image2.png)

**Figure 3.** Comparison between the variation of oil valve opening degree and its simulation.
Figure 4. Comparison between the variation of steam turbine power and its simulation.

Figure 5. Comparison between the variation of gas turbine outlet temperature and its simulation.

The simulation results are in good agreement with the measured data. The nonlinear fitting relative errors of the variation of gas turbine power, oil valve opening degree, and gas turbine outlet temperature are all within 10%, and the curve conforms to the dynamic characteristics of the combined cycle unit. However, the difference in identification results of steam turbine power change is due to the fact that in the actual production process, due to the disturbance inertia before, the initial signal produces a continuous rising change, which also results in a relatively large pure delay time constant.
of the steam turbine, which has a certain impact on the system. In this paper, the traditional genetic algorithm is compared with the improved quadratic fitness genetic algorithm. It is obvious that the improved genetic algorithm is closer to the real data in consistency and has higher reliability.

4. Conclusions
In this paper, based on the typical mathematical equivalent model of gas-steam combined cycle unit, an improved genetic algorithm is proposed and used to identify the core parameters of the model structure for four representative thermal process models. The results show that the simulated data are in good agreement with the measured data, and the relative error is less than 10%. Especially in the simulation of steam turbine power change, compared with the traditional genetic algorithm, the improved algorithm in this paper has a higher degree of nonlinear coincidence and can better reflect the dynamic characteristics of the system.

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References
[1] Gao Yang. Dynamic Model and Simulation of the Gas Turbine Based On Combined Cycle, Chong Qing University[D]. 2002.
[2] Gao Lin, Xia Junrong, Dai Yiping. Research on the mathematic model of a combined cycle power plant and its parameter identification[J]. 2009, 22(4):35-39.
[3] Gao Lin, Xia Junrong, Dai Yiping, Kan Weimin. Modeling and Identification of Combined Cycle Units Based on the Genetic Algorithm[J]. 2010, 4(4):34-37.
[4] Qiu Xiaozhi, Wang Wei, Si Peiyou, Huang Baohua. Parameter Discrimination of a Combined Cycle Unit Based on the Genetic Algorithm[J]. 2012,27(5):549-553.
[5] Kazuhiro Baba, Naoto Kakimoto. Dynamic behavior of a combined cycle power plant in the presence of a frequency drop[J]. Electrical Engineering in Japan. 2010, 143(3):9-19.