Optimization of Valve Flow Characteristics Based on Improved Particle Swarm Algorithm

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Abstract. After long-term operation, the flow characteristics of the high-pressure regulating valve of a thermal power unit may be shifted to a certain extent, resulting in inconsistent changes in the total valve position and opening degree, which in turn affects the PFR function of the unit. Based on the historical operation data of a thermal power unit, the flow characteristics of the unit's high-pressure regulating valve are optimized using an improved particle swarm algorithm. By experimentally verifying the primary FM in different total valve position intervals, the influence of valve flow characteristics on the primary FM function is discussed. The results of the primary FM example show that, with the optimized valve flow characteristics, the output response index of the unit in 15 and 30 seconds is increased to 85.44% and 94.11%, respectively, which meets the assessment requirements of the grid-connected operation and management of the power plant for the primary FM, and optimizes the primary FM performance of the unit.

1 Introduction

By adjusting the opening of the high-pressure control valve of the steam engine, the PFR function of thermal power units utilizes the heat storage of the unit to realize power increase and decrease, in order to balance the power generation and load demand, and maintain the grid frequency within the specified range. In order to meet the synergistic demand among grid, source and load, the primary FM performance of thermal power units is crucial for the safe and stable operation of the grid and should be used as an important power auxiliary service. As a matter of fact, this auxiliary service has gone through a reform from gratuitous provision to marketization. In view of the new characteristics of the current power energy structure, the necessity of upgrading auxiliary services such as primary FM of thermal power units is self-evident[1-2].

The steam engine speed control system of large thermal power units usually adopts digital electro-hydraulic (DEH) control system. Steam flow control is achieved through the steam distribution function, which converts the flow change value into a high-pressure regulating valve opening signal, providing a high degree of flexibility[3]. However, as the unit operates for a long time, the valve is damaged and fatigue is aggravated, resulting in the flow characteristics of the high-pressure regulating valve deviating from the set value and destroying the correspondence between the total valve position command and the opening degree. This causes a local or overall deviation from the linear relationship between the opening degree and the total valve position command, which affects the quality of the primary FM and reduces the stability of the unit. Therefore, it is crucial to optimize the valve flow characteristics in the control loop in a timely manner[4].

Particle swarm algorithm (PSO) has obvious advantages in solving multidimensional constrained optimization problems with simple structure and fast convergence[5]. At present, the algorithm has been widely used in the study of PFR of thermal power units. Wang Ruoyu adopted the particle swarm algorithm for identifying unit characteristics and predicting the primary FM margin[6]. Tao Qian et al. analyzed the unit economics during primary FM and optimized the FM parameters by particle swarm algorithm to obtain the optimal coal consumption, so that the primary FM performance reaches the best level. At the same time, the flow characteristics of the high-pressure regulating valves of the relevant units are also rectified by particle swarm algorithm. The influence of the valve flow characteristics on the PFR function of the unit is discussed in depth[7].

To this end, this paper proposes a valve flow characteristic setting optimization method based on IPSO. First, from the IPSO. Then, it is applied to the valve characteristic rectification optimization of thermal power units. Finally, experimental verification is carried out.

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2 Valve Flow Characteristics of The Rectification Method

2.1. Improved particle swarm algorithm

The simulation of bird feeding behavior is implemented by particle swarm algorithm. In the search for an optimal solution, an initial swarm of particles is first randomly generated. Then, each particle tries to track and find its own optimal value, while the whole swarm pursues and updates the global optimal value. Then, these optimal values will be used to update the velocity and position of each particle. After continuous iterations and adjustments, the swarm will eventually converge and find the global optimum[8].

The basic particle swarm algorithm steps are:

1) Initialize the particle swarm.
2) Calculate the fitness value.
3) Calculate the model accuracy.
4) Update the velocity and position.
5) Step loop: loop over the above steps until the population fitness value meets the model accuracy requirement. Or the maximum number of iterations is reached, the loop is exited.

In the particle swarm algorithm, the particle velocity and position in the model are as follows:

$$\begin{cases} x_{i,k+1} = x_{i,k} + v_{i,k+1} \\ w = w_{\max} - \dfrac{(w_{\max} - w_{\min})k}{k_{\max}} \\ v_{i,k+1} = wv_{i,k} + c_1 r_1 (p_i - x_{i,k}) + c_2 r_2 (p_g - x_{i,k}) \end{cases} \tag{1}$$

Particle swarm algorithms are prone to fall into local extremes in the optimization search process. When recognizing multi-parameter objects, problems such as low efficiency and poor model accuracy occur. The main reason is that the inertia weights and learning factors in the basic PSO are constants. There is no dynamic adjustment ability, which can not be changed in real time with the iteration, resulting in the algorithm is easy to fall into the local optimum. In order to solve the above problems, this paper utilizes the traversal and randomness of chaotic mapping to realize the local deep search of the PSO and enhance its local optimization ability[9]. In this paper, the chaotic PSO is used for model parameter identification. Logistic chaos is chosen as the inertia weights in the chaotic PSO to enhance the optimization ability of the particle swarm[10].

The nonlinear equations for Logistic chaotic mapping are as follows:

$$x_{i+1,k} = F(x_i, u) = ux_{i,k}(1 - x_{i,k}) \tag{2}$$

where: u denotes the control parameter.

2.2 Application of Improved Particle Swarm Algorithm in Optimization of Valve Flow Characteristics Setting

The development of intelligent algorithms and the expansion of their application fields have made them play an important role in the calculation and analysis related to valve characteristics. The process of optimized tuning thus becomes faster and more accurate. Based on the historical data of a thermal power unit's sequential valve model, parameters such as total valve position command, main steam pressure, post-valve pressure, regulating stage pressure, and CV1-CV4 valve strokes were extracted in the Distributed Control System (DCS). And the valve opening-total valve position characteristic curve was constructed. An IPSO is introduced to perform the corresponding valve characteristic rectification analysis.

In the DEH control system loop, the design curve of the opening-total position characteristic of the high-pressure control valve is embedded in the system in the form of a polyline. The total valve position can be converted into the opening degree of each high-pressure control valve by the corresponding polyline function. The general and local operating conditions of the high pressure control valves can be analyzed by calculating the degree of fit of the model calibration. Depending on the degree of deviation of the opening of each valve from the design value, corresponding rectification can be carried out to improve the goal of flow characteristic linearity. In the rectification, the zone can be divided according to the interval deviation of the total valve position, and then judge the valve linearity in each interval in turn, and carry out the corresponding rectification.

IPSO techniques were used to set the valve characteristics. First, a fitting curve was created by fitting the total valve position and the opening of the high-pressure control valves from the historical data. Next, multiple particles were randomly generated in the vertical direction of this curve, with the horizontal coordinate of each particle representing the total valve position and the vertical coordinate representing the opening of each high-pressure control valve. The newly generated particles were used to calculate the valve openings at the total valve position. In order to find the best result, after several trials, the iteration termination mean square error value of 0.01 was set considering the calculation accuracy and calculation speed. Check the mean square error of the valve opening of the new valve opening and the valve opening of the design curve, and if the mean square error is greater than 0.01, automatically update the position of the particle according to the predetermined rules and repeat the above calculation process until the accuracy requirement is satisfied. Finally, the particles satisfying the accuracy were re-fitted to obtain the set opening-total valve position characteristic curve. According to this curve, the corresponding vapor distribution function was modified, thus completing the setting of the valve flow characteristics.

3 Case Study

3.1 Analysis of the impact of the flow characteristics of the regulator on the primary FM function of the unit

According to Fig. 1, it can be seen that the openness-total valve position relationship curve obtained by analyzing the historical operation data of a supercritical unit. It can be found that there is a certain error between the actual and the ideal characteristic curve of the high-pressure control valve of this unit.

Figure 1 demonstrates the overall performance between opening and total valve position. Although there is a somewhat linear relationship overall, some parts show a deviation from the ideal curve. This deviation from the ideal curve is due to fatigue or wear of the valve due to long-term use, which makes the actual single-valve performance deviate from the design value. The original valve management function has not been optimized accordingly, resulting in poor linearity between opening and total valve position. Especially for valves that are frequently operated on a daily basis, the probability of such nonlinear characteristics increases accordingly.

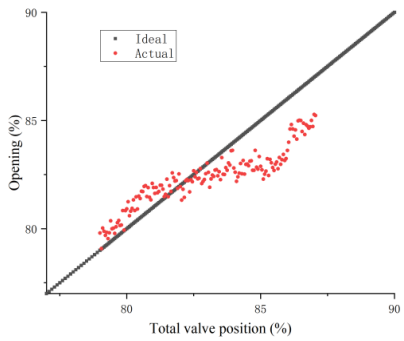

Fig. 1. Relationship curve of opening degree - total valve position.

According to the actual situation, the total valve level is divided into three parts. The first part is 79% to 82%, the second part is 82% to 84%, and the third part is 84% to 87%. The opening of the first part is very much in line with the ideal characteristics. The opening of the second part is slower compared to the ideal. The opening of the third part has more ups and downs overall compared to the ideal situation.

Experimental Setup: In order to study the influence of 3 intervals of opening-total valve position characteristic curves on the primary FM action, the corresponding primary FM events were selected from a large amount of historical operation data for detailed analysis. In selecting the FM segments, the following conditions are followed: 1) The perturbation causing FM is regarded as an effective perturbation. 2) The direction of one FM action is correct. 3) Selecting FM segments with the same time interval and similar valve step quantities for comparative analysis. Specific experimental results are detailed in Figure 2.

The unit is FM'd at 21:22:19-21:23:19, 16:12:05-16:13:04 and 17:33:18-17:34:17 on a certain day.

Under the guidance of the "Two Rules", the grid's assessment of the unit's primary FM is becoming more and more stringent. The "Two Rules" take the 15-second power response index and 30-second power response index as important indicators for evaluating the performance of primary FM of a unit. Calculate the corresponding one-time FM example in the above three intervals, and the results are shown in Table 1. The "two rules" stipulate: Thermal power units with 15-second output response index less than 75% are unqualified. A 30-second power response index of less than 90% is unqualified.

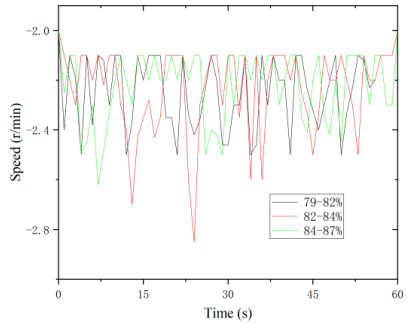

Fig. 2. The situation of primary FM in different valve level intervals.

Table 1. Evaluation of primary FM performance in different zones.

Project	Total valve position 79-82% range	Total valve position 82-84% range	Total valve position 84-87% range
15s output response index	78.55	23.53	93.88
30s output response index	94.44	51.18	99.85

Table 1 shows that: 82%~84% The primary FM situation in the zone does not meet the assessment requirements. This is consistent with the opening degree - total valve position characteristic curve in this interval.

3.2 Case Validation

Combined with the actual operation of the four high-tuning valves, CV1-CV4, the degree of opening of the CV3 valve is the main factor affecting the overall valve flow characteristics in the range of 82% to 84% of the total valve position, while the influence of the CV1, CV2, and CV4 valves is negligible. Therefore, the characteristic relationship between the degree of opening and the total valve position is improved by adjusting and optimizing the characteristics of the CV3 valve in order to improve the primary FM performance of the unit in this range.

To achieve this goal, an IPSO is used for the tuning optimization. Some of the main parameters of this algorithm are set as follows: The relationship between the CV3 valve opening and the total valve position is shown in the DEH control system of the case unit as 11 dimensions, so the particle dimension is also set to 11. The position range is set to [0,100]. The velocity range is set to [-1,1]. The learning factor c_1 and c_2 are both set to 0.5. The particle population size is set to 500. The

number of iterations is set to 500 to ensure the computational accuracy.

The optimized CV3 valve characteristic curve is shown in Fig. 3 with the total valve position as the horizontal coordinate and the CV3 valve opening as the vertical coordinate. Fig. 4 shows the opening and total valve position characteristic curves after optimization by particle swarm algorithm. The overall curve is smoother and has a similar slope to the curve in the 79% to 82% range. The optimized curve results in improved stability of the unit.

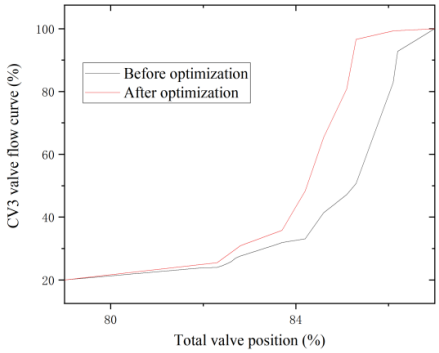

Fig. 3 CV3 valve flow curve before and after optimization.

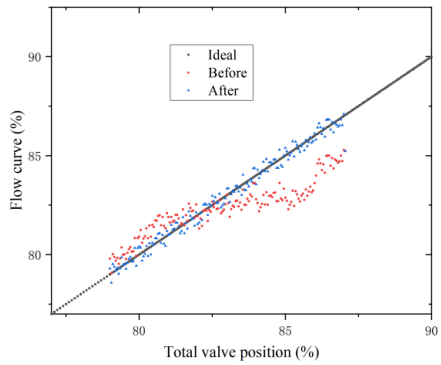

Fig. 4 Openness-total valve position characteristic after optimization.

According to the calculation results of the primary FM output response index of the optimized unit, it is shown: When a certain FM occurs in the 82%~85% interval, the unit's output response index increases to 85.44% for 15s and 94.11% for 30s. It can be seen that the optimized characteristic curve is beneficial to the regulation of the high-pressure regulating valve and improves the control accuracy of the high-pressure regulating valve for one frequency adjustment.

4 Conclusion

When the unit is operated in a certain interval of the total valve position for a long time according to the sequential valve control mode, the valve characteristic of a certain high-pressure regulating valve deviates from the design expectation, which in turn affects the performance of the unit's primary FM. If the deviation of the valve characteristics leads to a small valve opening value under the same total valve position command, the problem of insufficient primary FM output is triggered. This is manifested in the fact that the output response indices of 15 and 30 seconds cannot meet the assessment criteria. However, the valve characteristics can be effectively optimized by PSO. Thus, the output response index of the primary FM function at all stages can meet the assessment requirements and improve the overall performance of the unit's primary FM.

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