Application of Load Optimization Control of Thermal Power Unit Based on the Characteristics of Regulating Valve

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Abstract. In the long-term operation of thermal power units, the nonlinear and more complex viscous faults often occur in the regulator valve, which have obvious adverse effects on the dynamic performance of the load control. By using two point line models and Presiach models that are switched to each other to describe the switch asymmetry of the regulating valve and the different viscosity characteristics, the viscous fault of the regulating valve is effectively diagnosed, and the statistical consistency of the estimated values of model parameters are proved. Several key control technologies of thermal unit are given, and the control method of compensating the viscous fault of the regulating valve is presented, which weakens the adverse effect of the non-linear characteristics of the control valve on the dynamic control performance, and makes the main variables such as main steam pressure of unit achieve good dynamic performance.

1. Introduction

With the further acceleration of China's energy structure transformation, low-carbon economy and clean energy will develop rapidly. At the same time, the large-scale development of clean energy such as wind power also increases the pressure on the safe and stable operation of power system. The fluctuation of new energy power will have a great impact on the continuous, reliable power supply and safe operation of the power grid. Therefore, conventional thermal power and hydropower must be able to stabilize fluctuations and assume the task of peaking the power grid.

By complementing the volatility of multiple energy sources, complementary power supplies are required to have a certain response speed, while also ensuring the economics of their own wide range of variable load operation. In Japan and some European developed countries, hydropower accounts for a high proportion, is the main means of peak regulation. In the United States, gas and oil power generation capacity accounts for more than 45% of installed capacity, which is the primary choice for peak regulation. However, in China, coal-fired thermal power generation plays a major role in power supply. At present, the large-scale development of new energy sources must depend on the rapid and deep load regulation of thermal power units. However, the problems of narrow adjustable range and slow adjustment speed of the current thermal power units are prominent, and the operation of a large range of variable load will lead to a significant decline in its economy, safety and environmental protection[1-4]. In order to satisfy the demand of stabilizing the fluctuation of new energy, it is necessary to construct the fine characterization method of important links, and lay a foundation for the rapid and accurate control of the power generation process[5,6]. Secondly, it is necessary to optimize
the load control scheme of thermal power units, so as to improve the variable load control rate of units, and finally form the fast and deep variable load control strategy of large thermal power units.

2. Problem and Characteristics of Regulating Valve

When the actual power of the power grid changes rapidly in a wide range, boiler, turbine and auxiliary equipment of thermal power unit will change between different work status, which means that the control circuit of controlled object or interference channels can present strong nonlinear characteristics. The regulating valve will move in a large travel range, also has strong nonlinear characteristics, which has a significant impact on the dynamic performance of the control loop.

2.1 Existing problems

Control valves in process industries possibly present various nonlinearities, which may degrade control performance or even cause oscillations arisen in closed-control loops. Industrial surveys[7-10] indicate that about 20-30% of control loops oscillate due to valve nonlinearities, such as stiction, hysteresis, dead-zone or dead-band.

The main causes that influence the dynamic performance of the control loop include three reasons: mismatched controller parameters, improper control strategy and nonlinear characteristics of the regulating valve. The first two reasons can be judged by the performance evaluation results, in the case that the control strategy remains unchanged, if the performance evaluation results are poor, the dynamic characteristics of the controller parameters do not match the controlled object and interference channel, and the controller parameters need to be adjusted to adapt to the nonlinear characteristics of the controlled object and interference channel. On the contrary, if the performance evaluation results are good, the control strategy(such as adding feed-forward link) will be re-evaluated. If the re-evaluation results are poor, it indicates that adjusting the control strategy can greatly improve the performance of the control loop. The third reason is difficult to judge and the non-linear characteristics of actuators need to be systematically studied. The actuator mainly includes the regulating valve, frequency conversion pump and motor, etc., among which the regulating valve occupies the leading position and is the most used actuator in the process industry.

2.2 Preisach system identification

Firstly, the Preisach model was discretized, and the Preisach model in discrete form was obtained as

\[ x(t) = \sum_{i=1}^{L} \sum_{j=i}^{L} \mu_{ij} \gamma_{ij}(t) \]

Where, \( \mu_{ij} \) is the weight parameter in the discrete form, and \( \gamma_{ij}(t) \) is the relay operator in the discrete form.

\[ \gamma_{ij}(t) \doteq \begin{cases} +1, & \text{if } u(t) > \frac{u_j + u_j + 1}{2} \\ -1, & \text{if } u(t) < \frac{u_i + u_i + 1}{2} \\ \gamma_{ij}(t-1), & \text{otherwise} \end{cases} \]

Here \( u_i \) is the discrete input threshold, \( u_i \doteq u_{\min} + (i - 1) \delta, \ i = 1, 2, \ldots, L + 1 \).
\( L \) represents the level of discretization, \( \delta \) represents the step size of discretization,
\[
\delta \triangleq \frac{u_{\text{max}} - u_{\text{min}}}{L}
\]

The expression of the input nonlinear module \( f[\mu, \zeta](\cdot) \) described by the Preisach model is,
\[
f[\mu, \zeta](t) = \int_{\beta, \alpha} \mu(\beta, \alpha) \gamma_{\beta, \alpha}[\mu, \zeta](t) \, d\beta d\alpha
\]

Regulating valve direct contact with the production medium, often by the impact of the medium and corrosion, and valve stem and other mechanical parts in a large number of round-trip movement is prone to wear. Therefore, with the increase of service time, the non-linear proportional relationship between stem position and valve flow often occurs in the regulator, as well as more complex viscous faults, which have obvious adverse effects on the dynamic performance of the control loop. The difficulty of the nonlinear characteristic of the control valve lies in the mathematical model describing the viscous fault of the control valve. The models of relevant research results at home and abroad are mainly divided into two categories, mechanism model and data-driven model. The mechanism model is mainly based on Newton's second law of motion and the principle of force balance. It is a dynamic nonlinear differential equation, which requires multiple physical parameters such as stem weight, spring elasticity coefficient, etc. However, these parameters are difficult to obtain in the industrial environment. Compared with that, the data-driven model describes the input and output relationship of the regulator valve, which has simple model structure and few parameters and can be obtained by the model identification method. However, there is a prominent bottleneck problem in the existing data-driven model, the existing mathematical model of the regulator has limited capacity, which can not be used to diagnose the common switch asymmetry of the regulator, the stickiness degree of different stem positions of the stickiness fault.

Aiming at the bottleneck problems mentioned above, a new mathematical model and model identification method of the control valve are proposed, which can effectively diagnose the viscous fault of the control valve. The two-point line model and Preisach model were used to describe the switching asymmetry of the regulator valve and the non-linear characteristics with different stickiness degree of different stem positions. Blind identification method and other modular identification methods of the non-linear model were proposed to prove the statistical consistency of the estimated values of model parameters. The Preisach model is flexible, in particular, it is suitable to describe the
complex characters of sticky control valves under oscillatory or more general input signals. The proposed model and the corresponding identification method have been successfully applied in the field throttling valve, as shown in figure 2, 10 typical industrial applications. It can accurately quantify the stickiness of the valve and the nonlinear proportional relationship between stem position and valve flow.

3. Control Method Optimization

When the nonlinear viscous fault exists in the regulating valve, the viscous fault can be removed by replacing or maintaining the control valve, but these work can only be carried out during the shutdown maintenance, so it is necessary to adjust the controller parameters or control strategy and other technical means, to compensate for the negative impact of the regulating valve viscous fault on the dynamic control performance.

When the thermal power unit is connected to the power grid, the control mode is generally at CCS (coordinated control system) mode. The steam turbine side passes through the main control loop of the steam turbine, so that the active power can quickly and accurately track the change of the load instruction of the power grid, while the boiler side controls the main steam pressure and temperature within the appropriate range through the main control loop of the boiler.

Figure 3. The load optimization control logic of CCS mode

The active load of unit need to change rapidly when the frequency of power grid fluctuate, but the response of the regulating valve have delay and inertia, so, when the unit’s load demand has a change, the turbine regulating valve should adopt an appropriate action valve to meet the unit’s load demand. In CCS mode, turbine master PID according to the deviation that setting value and the actual value of unit’s load to adjust, don't consider the speed and precision influence of the regulating valve and main steam pressure. According to the setting load generates a fixed proportion of turbine master's ratio feed-forward, this value of ratio feed-forward can be occupied 50%-70% of the turbine master total output, and the specific value according to the actual operation unit to decide. According to the setting load generates a PID's differential feed-forward, the difference come from the setting load minus its inertia LAG links. Set a module A, its value is the proportion Kp of turbine master PID. The new Kp of PID is A after pressure correction. While the proportional action is based on the current value of the control error and the integral action is based on the past values of the control error, the derivative action is based on the predicted future values of the control error. This naturally results in a PD controller. It appears that the derivative action has a great potentiality in improving the control performance as it can anticipate an incorrect trend of the control error and counteract for it.

4. Practical Application

Through the optimization control of generator turbine technology, and failure of the compensating regulator viscosity control method, weakens the dampers nonlinear characteristics and actual situation of adverse influence on the dynamic control performance, the flow of steam, fuel generating units, air, water and other main variables to obtain good dynamic performance. As shown in figure 4, by
adjusting the controller parameters and logic optimization, the fluctuation of main steam pressure was reduced.

When the load order of the power grid changes, it can guarantee that the load response rate, precision and response time of the unit have good performance.

Comparing before and after control optimization, it can be seen from Table 1, due to the interference of the regulating valve, will cause the loss of AGC (automatic power generation control) of indicators. After optimization of advance compensation, AGC index was significantly improved.

Table 1. Influence of PFC the regulating valve to AGC assessment indicators

| Date  | Speed  | Precision | Response Time | Comprehensive Performance Index | Compensation Fees (Million Yuan) |
|-------|--------|-----------|---------------|---------------------------------|---------------------------------|
| 09-23 | 1.178  | 1.093     | 1.700         | 2.293                           | 16.29                           |
| 09-22 | 1.187  | 1.149     | 1.707         | 2.344                           | 15.19                           |
| 09-21 | 1.195  | 1.145     | 1.705         | 2.392                           | 16.56                           |
| 09-20 | 1.182  | 1.148     | 1.691         | 2.298                           | 15.79                           |
| 09-14 | 1.021  | 0.896     | 1.662         | 1.513                           | 8.94                            |
| 09-13 | 1.015  | 0.940     | 1.668         | 1.743                           | 8.53                            |
| 09-12 | 1.017  | 0.914     | 1.666         | 1.480                           | 8.38                            |
| 09-11 | 0.993  | 0.950     | 1.660         | 1.646                           | 8.27                            |

5. Conclusion

In the long-term operation of thermal power units, the nonlinear proportional relationship between stem position and valve flow and more complex viscous faults often occur in the regulator valve, which has obvious adverse effects on the dynamic performance of the control loop. The Presiach model and two point-line models were used to describe the switching asymmetry of the control valve and the non-linear characteristics with different stickiness degree of different stem positions, which could effectively diagnose the stickiness failure of the control valve and proved the statistical consistency of the estimated values of model parameters. In this paper, several key control technologies of turbine side of generator set are given, and the control method of compensating the viscous fault of the control valve is presented, which weakens the negative influence of the non-linear characteristics of the control valve on the dynamic control performance and makes the main variables of the generator set achieve good dynamic performance. The results of operation practice show that the main indexes of the unit have been significantly improved.
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