Optimization of Sliding Pressure Curve of Thermal Power Unit Based on Economical and Primary Frequency Modulation Characteristics

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Abstract. According to the thermal economic characteristics and primary frequency modulation characteristics of the thermal power unit's variable working conditions, the nozzle distribution steam turbine unit is taken as the research object to meet the primary frequency modulation capacity and reduce the unit heat consumption rate. The influence of the valve position on the economics of the unit and the primary frequency modulation capability is used to provide a richer adjustment basis for the technical and economic comparison between different operating modes of the unit, and the obtained sliding pressure running curve can meet the requirements of primary frequency regulation of the power grid. The throttling loss generated during the operation of the unit is minimized, and the optimal configuration between the grid operation and the power economy is realized.

1. Introduction

Based on the rapid development of China's economy and the reality of the distribution of primary energy, the thermal power unit will remain the main force of China's power supply market in the next few decades, and it is also the main unit for power grid peaking. In the context of the increasingly deepening of power market reforms and the intensified contradiction between power supply and demand, whether from the development trend of the power industry or the development needs of thermal power, the positioning of coal-fired power plants in the system is transformed into a basic power supply that provides reliable power and peaking and frequency modulation[1]. Therefore, considering the economics of the unit operation and improving the frequency response capability of the unit will be an inevitable choice for the thermal power unit in the new situation.

The traditional optimization of thermal power unit is only one-sided considering the maximization of the unit efficiency, that is, the optimal main pressure of the unit under the load is selected based on the principle of the minimum heat consumption rate of the unit[2]. Therefore, the optimal operation mode obtained by the test is difficult to meet the needs of the actual peak-shaving operation of the unit, and even contrary to the safety of the power grid. In this paper, the multi-factors such as thermal economic characteristics, peak load and frequency regulation safety characteristics of steam turbines are analysed. With the wide-area thermal economic map identification of steam turbines, the optimal operating valve of the unit under various operating conditions is obtained, which provides a richer adjustment basis for the technical and economic comparison between the different operation modes of the steam turbine unit under the condition of deep peaking and frequency modulation.
2. Research on the overall economics of thermal power units

When the thermal power unit is running at a constant power, there is an inherent numerical relationship between the main steam pressure, the total valve position command, the regulating valve position, the relative internal efficiency of the high-pressure cylinder, and the heat consumption rate of the unit. The essence is due to the throttling characteristics of the steam turbine high pressure regulating valve. The regulating valve position is the main state parameter of the regulating valve, which has the dual properties of geometric and thermodynamic significance [3]. In the process of global transformer test, the continuous change process of steam inlet pressure in the predetermined valve opening sequence and constant power mode is the continuous change process of the valve position of the regulating valve. Theoretical and field tests show that there is a big difference in the thermal economic characteristics of the variable pressure operation of steam turbines with different steam distribution modes and valve opening sequence. The thermal economic characteristics of the variable pressure operation of steam turbines with the same steam distribution method and valve opening sequence is more similar. But it should also be pointed out that the thermal economic characteristics of the variable pressure operation of the steam turbine unit with the established steam distribution method and the valve opening sequence are often different under different electric powers.

Figure 1 shows the thermal economic characteristics of a N650-24.2/566/566 supercritical throttled steam distribution unit under 90% THA conditions, the unit is equipped with two high pressure main regulating valves and two supplementary steam valves. The opening valve sequence of the high pressure regulating valve is CV1/2→CV3/CV4. It can be seen from Figure 1 that the single valve point characteristic of the unit is due to the severe throttling of the steam supply valve.

For one thing, the thermal economic characteristics of variable pressure operation can show the inherent law of the constant load operation of the steam turbine unit, for another, it is closely related to the steam distribution mode, valve opening sequence and electric power of the unit. At the same time, whether it is a subcritical parameter unit or Supercritical parameter units have similar laws for the thermal economy of their variable pressure operation under the same valve opening sequence.

3. The effect of regulating valve throttling primary frequency modulation to the heat consumption rate

Under constant power, the main steam pressure of thermal power unit has a one-to-one correspondence with the total valve position command. The two determine the energy storage capacity of the unit, which plays a direct role in the rapid response of the primary frequency modulation [4]. Figure 2 shows the
initial main steam pressure, the initial total valve position command, and the maximum frequency modulation capability under 90% operating conditions.

Figure 2. Frequency modulation and valve characteristics of the unit under 90% THA conditions

Comparing the initial main steam pressure and the corresponding total valve position command under different frequency difference conditions, it is easy to see that the primary frequency storage energy has a surplus due to the excessive throttle of the regulating valve. According to the main steam pressure or the total valve position command in Figure 2, and with the aid of Figure 1, the change of heat consumption rate can be numerically quantified to meet the requirements of the primary frequency-modulated rapid load-increasing energy storage under the above conditions. Through the necessary constraints of thermal economy, it is possible to avoid excessive throttling of the main steam regulating valve, which is beneficial to guide the rational development of the primary frequency modulation work. Meanwhile, the technical and economic comparison between the different operating modes of the unit provides a more extensive test basis [5]. The relationship between the main steam pressure, the unit heat rate and the primary frequency modulation capacity of the unit under this condition is shown in Figure 3.

Figure 3. primary frequency and economic characteristics of the unit under 90% THA conditions

From Figure 3, when the main steam pressure is around 23.6 MPa under 90% THA conditions, the unit can meet the 6%Pe primary frequency modulation capacity, and has a relatively low heat consumption rate [6]. On the other hand, in order to ensure the primary frequency capability of the unit
under this condition, the unit's valve command needs to be reduced from 97% to about 71%, and the heat consumption rate of the unit is from the lowest of 7990.4kJ/kW. h rises to 8004.0kJ/kW. h.

4. Optimization of sliding pressure curve based on economy and primary frequency characteristics

In order to ensure the primary frequency capability of the unit under various working conditions, and to have a relatively low heat consumption rate of the unit, the optimal position of main regulating valve corresponding to different loads under the new valve sequence is obtained by optimizing the adjustment test of the operation mode. From Figure 4, we can see that the main steam pressure after optimization in the 480MW~300MW condition is increased by 1.44MPa compared with the previous one, which significantly increases the energy storage level of the unit under the load section, which is beneficial to the unit's primary frequency modulation. The responsiveness reaches the grid frequency modulation demand, but at the same time it also increases the unit's heat consumption rate, which makes the unit economic decline [7].

![Figure 4. Comparing curve of slide pressure before and after optimization](image)

Table 1 variable pressure operation setting value

| project | unit | setting value |
|---------|------|---------------|
| Unit load | MW | 640 585 480 400 300 |
| Main steam pressure (original) | MPa | 24.2 22.8 20.09 17.36 13.65 |
| Main steam pressure (optimized) | MPa | 24.2 23.6 21.1 18.77 15.65 |
| Increase in Main steam pressure | MPa | 0 0.8 1 1.41 2.0 |
| Increase in heat consumption rate | kJ/kW. h | 0 14 24 35 46 |

The optimized calculation of the sliding pressure curve is applied to the actual operation of the unit. In the month before the adjustment of the sliding pressure curve, electricity quantity checked by primary frequency modulation is $192 \times 10^4$kWꞏh, which is equivalent to RMB 770,000[8]. In the month after adjustment, only $24 \times 10^4$kWꞏh was assessed, reducing the economic loss of the power plant by RMB 660,000. From the results, although the optimized operating conditions sacrificed a certain unit economy,
the unit's primary frequency modulation capability was improved, and the crew was responsible for ensuring the stability of the grid frequency.

5. Conclusion

For the nozzle throttling and distribution unit, certain main valve position and supplementary valve position correspond to certain thermal economy and primary frequency modulation energy storage. In order to meet the requirements of generator-network harmonization, it is necessary to sacrifice a small amount of unit thermal economy.

The research on the sliding pressure curve based on economic and primary frequency modulation characteristics proposed in this paper has important guidance and practical significance for the operation of thermal power generating units under the current dispatch mode. This method can guarantee the meeting of the primary frequency regulation requirements of the power grid. Under the premise, the throttling loss generated during the operation of the throttle distribution unit is minimized, and the optimal configuration between the grid operation and the power economy is realized.

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