Study on economics of depth peak-shaving for 1000MW ultra supercritical unit

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Abstract. With the increase of the demand for deep peak regulation of power grid, large-capacity units have the advantages of strong peak regulation capacity. 1000MW units have been widely involved in deep peak regulation. In the process of deep peak regulation, the actual working condition of the unit deviates greatly from the designed working condition, and the unit efficiency decreases significantly, making the unit economy deteriorate seriously, especially in the 1000MW grade unit. In this paper, a 1000MW unit depth peak adjustment is experimentally studied and its economic indexes are calculated. Then, by analyzing the test data, the optimization Suggestions for the operation of the unit during the depth peak adjustment are put forward:(1) Improve the opening of the high pressure switch of the unit to reduce throttling loss and improve the unit efficiency; (2) Increase the reheat steam temperature to ensure the stable operation of the reheat steam temperature at 620°C of the full load section; (3) Keep a circulating pump running at a low speed during deep peak adjustment to reduce power consumption.

1. Introduction
With the rapid growth of ultra-high voltage power transmission capacity across the region and the priority of grid connection with wind power, hydropower, solar power, nuclear power and other new energy sources, the average load rate of conventional thermal power units had been decreasing year by year. However, the task of deep peak regulation was increasing year by year, and the depth of peak regulation operation was greatly increased [1]. Because of the deep peak regulation capacity of large capacity units, the peak regulation operation became a common phenomenon. In the process of deep peak regulation, the actual working condition of the unit deviated greatly from the designed working condition, and the unit efficiency decreased significantly, making the unit economy deteriorate seriously, especially in the 1000MW unit. Analysis for 1000MW grade unit in the depth of peak shaving of economy, this article selected the Shanghai steam turbine factory in the production of N1013-28/600/620 ultra-supercritical, a reheat, single axis four cylinder four exhaust steam, the condensing steam turbine thermal test research, calculates the economic index of the unit, and affecting the unit and can be eliminated by optimizing operation factors were analyzed, and treatment suggestions were also given.
2. Depth peak adjustment economic indicators

2.1. Test profile

In order to analyze and compare the economy of the unit during deep peak regulation, the performance test of an ultra-supercritical 1000MW unit was carried out in this paper. The pure condensate 1000MW, 850MW, 700MW, 550MW and 400MW working conditions were carried out. The 550MW and 400MW working conditions correspond to 54.3% and 39.5% of the rated capacity of the unit respectively, and the 400MW working condition can be considered as the typical working condition of the unit's deep peak adjustment. The steam turbine test was conducted in accordance with GB/T 8117.2-2008 "steam turbine thermal performance acceptance test regulations", and the boiler efficiency test was conducted simultaneously in accordance with GB/T 10184-2015 "power station boiler performance test regulations", respectively calculating the heat consumption rate of the unit, high and high pressure cylinder efficiency, and coal consumption rate. Main test results are shown in Table 1:

| Name                      | 550MW   | 400MW   |
|---------------------------|---------|---------|
| Main steam pressure (MPa) | 16.24   | 13.53   |
| Main steam temperature (℃)| 596.71  | 597.11  |
| High pressure valve opening (%) | 30.40  | 23.82   |
| Exhaust steam pressure (kPa) | 3.83   | 3.45    |
| Feed water flow (t/h)     | 1449.36 | 1062.36 |
| HP cylinder efficiency (%) | 82.54   | 77.87   |
| IP cylinder efficiency (%) | 91.22   | 91.24   |
| Heat rate (kJ/kW.h)       | 7839.29 | 8129.08 |
| Boiler efficiency (%)     | 94.24   | 93.03   |
| Gross coal consumption rate (%) | 286.70 | 301.16  |
| Power supply coal consumption rate (%) | 301.34 | 320.93  |

2.2. Comparison of economic indicators

In the process of deep peak adjustment of the unit, the economic indexes that can reflect the unit are mainly boiler efficiency, steam turbine heat consumption rate and power utilization rate, and ultimately all influencing factors will be attributed to the coal consumption rate of power supply [2]. Fig. 1 shows the variation trend of coal consumption rate of power supply from 400MW working condition to 1000MW working condition. It can be seen from Fig. 1 that, with the reduction of load, the coal consumption rate of power supply gradually increases, especially in the section from 550MW to 400MW, the coal consumption rate of power supply suddenly rises, indicating that the economic performance of the unit deteriorates rapidly during the deep peak adjustment in the load rate range from 40% to 55%.

When the unit depth peak adjustment is conducted, the coal consumption rate of power supply of the unit increases by about 19.59g/kw.h when compared with 550MW, the standard coal is calculated at 800 CNY/t, and the fuel cost of the unit increases by about 0.01567 CNY/kw.h when compared with 550MW. Compared with 1000MW, 400MW's coal consumption rate increased by 33.03g/kw.h, and the fuel cost increased by 0.026 CNY/kw.h.
3. Economic factors are affected by depth peak adjustment

Through the analysis of the unit test data, found that some factors that influence the depth of the peakload economy but need to lift cylinder unit overhaul to eliminate, such as the interstage leakage flow part of scaling, results in the decrease of cylinder efficiency, such as feed water bypass leakage, low side inside the system such as leakage valve leakage, such as small machine cylinder efficiency to reduce steam consumption increase caused by small machine, etc., These factors are restricted by objective conditions and cannot be eliminated in a short time. Therefore, this paper didn’t analyze. At the same time, some economic factors that can be eliminated through operation optimization are also found, which are easier to solve to improve the economy of deep peak regulation. This paper analyzed them.

3.1. Main steam pressure and high pressure valve opening

For the full-cycle steam inlet unit, in the design working condition, the unit should run with sliding pressure with two valves fully open, so as to ensure the most economical operation of the unit. However, in actual operation, the adjustment valve is often not fully open, making the main steam pressure of the unit higher than the design value. In this paper, according to the relationship curve of main steam flow-power and main steam flow-pressure provided by the manufacturer, and combined with the test data, the relationship curve of main steam pressure and power under the design working condition and the actual working condition in Fig. 2 is obtained. Meanwhile, the deviation between the actual value of main steam pressure and the design value is calculated in Table 2:

![Fig. 1 Variation curve of coal consumption rate of power supply with load](image)

### Table 2. High pressure valve opening and deviation of main steam pressure

| Name                              | 1000MW | 850MW | 700MW | 550MW | 400MW |
|-----------------------------------|--------|-------|-------|-------|-------|
| High pressure valve opening (%)   | 42.56  | 32.58 | 31.39 | 30.40 | 23.82 |
| Deviation of main steam pressure(%)| 5.22   | 9.51  | 10.95 | 12.07 | 26.12 |
As can be seen from Table 2, with the reduction of load, the opening degree of the high adjustment gate decreases, and the deviation rate of the main steam pressure becomes larger and larger. When it reaches 400MW, the opening degree of the high adjustment gate is only 23.82%, and the deviation rate of the main steam pressure is as high as 26.12%. At this time, the unit is far away from the economic operation point. The valve opening is small, the throttle loss is large, the high pressure cylinder efficiency of the unit is low, the energy consumption increases. Therefore, it can be seen that the coal consumption rate of the unit during the depth peak adjustment can be reduced by increasing the valve opening. However, considering that the unit needs to keep a certain high valve opening to meet the requirements of primary frequency regulation of the power grid at the same time, the valve opening can be optimized to maintain the operation between 30% and 45% [3].

### 3.2. Reheat temperature

The designed reheat steam temperature of the unit is 620°C. As can be seen from Table 3, the reheat steam temperature in all working conditions during the test did not reach the design value, especially when load reduction was adjusted. During the test, the unit load was reduced to 400MW, and the reheat steam temperature was once as low as 590°C. According to the modified curve of reheat steam temperature on heat consumption rate and power provided by the manufacturer, every 5°C lower reheat temperature increases the heat consumption rate of the unit by 6.36 kJ/kw.h, increases the coal consumption by about 0.24g/kw.h, and reduces the unit output by 3.84MW. At 400MW, the reheat steam temperature is 12.26°C lower, coal consumption increases by about 0.59 g/kw.h, and unit output decreases by 9.41 MW. Thus, it can be seen that the designed value of reheat steam temperature of the unit increases to 620°C, which has very significant economic benefits.

| Name             | 1000MW | 850MW | 700MW | 550MW | 400MW |
|------------------|--------|-------|-------|-------|-------|
| Reheat temperature (°C) | 614.31 | 614.21 | 614.61 | 612.44 | 607.74 |

![Fig. 2 Relationship curve between main steam pressure and power](image-url)
At present, ultra-supercritical units with grades of 600MW and 1000MW and designed reheating steam temperature of 620°C in operation in China generally have sub-standard reheating steam temperature, which is mainly limited by the high temperature reheater wall at the furnace side. Literature [4] through such measures as "unbalanced" operation adjustment technology, make certain to ensure the full load of 660 mw ultra-supercritical period of reheat steam temperature of 620 °C under stable operation, provides can draw lessons from the experience, and the literature of the boiler and boiler in this paper is exactly the same manufacturer production of the same type boiler, suggest learning research unit.

3.3. Power utilization and back pressure

![Fig. 3 Power utilization rate under different conditions](image)

The unit is equipped with high and low pressure condenser, double back pressure operation, a total of three circulating water pumps. According to the requirements of the operating regulations, both the 550MW and 400MW operating conditions were operated at low speed by the two circulating pumps. As can be seen from Fig.3, the auxiliary power consumption rate increased significantly from 550MW to 400MW. The auxiliary power consumption rate of the 400MW operating condition was 6.16%, 1.3 percentage points higher than that of the 550MW operating condition.

The two circulating pumps operate at a low speed, 400MW compared with 550MW. At 400MW, the main steam flow rate is small and the condenser thermal load is low, but the back pressure of the main engine only decreases by 0.38kPa, indicating that increasing circulating water flow has a limited impact on reducing back pressure. At the same time, according to the revised curve of back pressure on heat consumption rate provided by the manufacturer, when the back pressure of the unit is at 4.9, the curve is very gentle, and reducing back pressure in this range has very little impact on improving unit economy. Back pressure is too low, and unit unit may be the cause of low pressure cylinder bearing vibration increase [5], the main reason is that low back pressure to low pressure cylinder body deformation, dynamic and static friction, and low pressure cylinder connected to the condenser, exhaust temperature change with vacuum, make the level of low pressure cylinder also produces change, changed the clearance between the rotor and cylinder.
Table 4. Back pressure under different conditions

| Name                                | 1000MW | 850MW | 700MW | 550MW | 400MW |
|-------------------------------------|--------|-------|-------|-------|-------|
| High condenser back pressure (kPa)  | 6.66   | 6.00  | 4.89  | 4.05  | 3.42  |
| Low condenser back pressure (kPa)   | 4.53   | 4.25  | 3.75  | 3.61  | 3.48  |
| Average back pressure (kPa)         | 5.60   | 5.12  | 4.32  | 3.83  | 3.45  |

In order to ensure the safety of the unit, it is stipulated in the operating regulations of the power plant that when the low pressure condenser back is lowered to 3.5kPa, the high and low pressure condenser contact door needs to be opened to make the unit run from double back pressure to single back pressure. As can be seen from Table 4, the unit operates under double back pressure when the load is 550MW or above, and single back pressure when the load is 400MW. According to the design of double back pressure unit, the economy of double back pressure unit is generally higher than that of single back pressure unit.

To sum up, the low speed operation of the two circulating pumps at 400MW does not reduce the back pressure of the unit much, but increases the power utilization rate of the unit and the potential vibration risk, and increases the coal consumption rate of the power supply of the unit. In order to improve the economy of the depth peak regulation of the unit, it is suggested to improve the operation level and actively explore the low speed operation of single circulating water pump at 400MW.

4. Conclusion

In order to analyze the economy of deep peak regulation of 1000MW unit, this paper selected a 1000MW ultra-supercritical unit for deep peak regulation test. According to the test results, the coal consumption rate of the power supply of the unit increased by about 33.03 g/kW.h and the fuel cost increased by about 0.026 CNY/kW.h when the unit was operating under 400MW condition, namely 40% load. Then, this paper analyzes the factors that affect the depth peak regulation economy of the unit and can be eliminated through optimized operation, and gives some suggestions:

1) The excessively low valve opening and large throttling loss of the unit result in high main steam pressure of the unit, low high pressure cylinder efficiency of the unit and increased energy consumption. At the same time, considering the needs of the unit to meet the requirements of primary frequency modulation of the power grid, the switch needs to keep a certain opening, which can be maintained between 30% and 45% by optimizing the switch curve.

2) The reheat steam temperature of ultra-supercritical units designed at 620℃ is generally substandard. Units of 400 MW, the reheat steam temperature is low 12.26℃, coal consumption increased about 0.59 g/kW h, reduce the output of generating unit 9.41 MW, visible raise the design value of the reheat steam temperature to 620℃, has very significant economic benefits, suggest use relevant successful experience, through the implementation of the "unbalanced" operation adjustment technology measures to ensure full load period of reheat steam temperature of 620℃ under stable operation.

3) When the unit is 550MW and 400MW, the two circulating pumps operate at low speed, which makes the power utilization ratio of the plant 1.3 percentage points higher than that of the 550MW unit under the condition of 400MW, but the back pressure only decreases by 0.38kpa. It is suggested to actively explore the low-speed operation of a single circulating pump under the condition of 400MW

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