Study on load adjustment range of 150 MW unit in heating season after high back pressure reform

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Abstract. New energy is experiencing rapid development, but it brings great challenges to peak shaving of power grid. Especially in the stage of wind power outbreak in winter, the operation mode of heat supply unit "fixing electricity by heat" aggravates the difficulty of peak shaving of power grid. Taking 150 MW double-extraction heat-supply unit as an example, the load adjustment intervals under different heating modes are enumerated by field test method for reference of power generation enterprises and power grid dispatching operation.

1. Background
According to the State Grid Energy Research Institute, the installed capacity of new energy will exceed that of thermal power by 2035. In 2035, the installed capacity of new energy was 1.43x10^4GW, accounting for 17% to 38% of the total installed capacity in 2017, and the proportion of new energy to total power generation was from 7% to 23% when the generating capacity was 2.7x10^7GW·h. On the one hand, new energy sources such as wind power and photovoltaic power provide us with a lot of clean electricity; on the other hand, the randomness and instability of their power generation also bring great challenges to the safe operation of power system and the guarantee of power supply [1], especially in the stage of winter wind power outbreak, the operation mode of heating units "fixing electricity by heat" The difficulty of peak load regulation is aggravated [2]. Therefore, it is necessary to find out the actual load carrying capacity of cogeneration units in the heating season, and find out the peak regulation range of units on the basis of guaranteeing people's livelihood of heating [3]. In this paper, a 150 MW double-extraction heat supply unit is transformed into a high back pressure one, and its load adjustment intervals under different heating modes are enumerated by means of field tests.

2. Brief introduction of heating system

2.1. Equipment renovation
The unit is an ultra-high pressure, primary reheating, double-cylinder, double-exhaust, single-axis and condensing-extraction steam turbine (two-stage adjusting steam extraction). The unit model is N150/CC135-13.24/535/535/0.981/0.23. Because of the need for low vacuum heating, the unit type after transformation is ultra-high pressure, one-stage reheating, double-cylinder and double-exhaust steam, single-axis and pumping. Steam condensing high back pressure heating steam turbine, the unit model is...
This retrofit keeps the existing boiler parameters and the high and medium pressure flow passage unchanged. Only the low-pressure module is retrofitted to realize the requirement of the low-pressure module with double back pressure and double rotors exchanging high back pressure heating operation. After modification, the condenser was replaced by N-9100 type condenser, and the low pressure cylinder was changed from $2\times 6$ to $2\times 4$. During winter operation, the normal operation vacuum is 51kPa, the rated vacuum is 47kPa, the minimum operation vacuum is 43kPa, the alarm vacuum is 39kPa, the boot vacuum is 34KPa, and the maximum operation vacuum is 81kPa. The designed heat network circulating water volume is 6000t/h, the inlet water temperature is 55°C, and the outlet water temperature is 78°C (vacuum 51kPa)/80°C (vacuum 47kPa).

2.2. Heating situation of the whole plant

There are four cogeneration units with a total installed capacity of 590 MW. Unit 1 is 110 MW unit, rated evaporation 410 t/h, rated heat supply extraction steam flow 392 t/h, Unit 2, 3 and 4 is 160 MW unit, rated evaporation is 480 t/h, rated steam intake is 484 t/h, super high pressure secondary adjustment steam extraction of steam turbine can take heating extraction steam and industrial extraction steam, designed maximum heating extraction steam flow is 240 t/h, quota. The constant flow rate is 210 t/h, the maximum industrial extraction capacity is 100 t/h, the rated flow rate is 60 t/h, the heating extraction parameters are 0.23MPa, 190°C, and the industrial extraction parameters are 0.98MPa, 342°C. Units 2 and 4 are transformed into high back pressure heating units respectively.

In the first battle of heating, there are 14 basic heaters, 7 basic condensate heaters, 1 deaerator, 12 circulating water pumps (1-10 are speed-regulating pumps, 11-12 are constant-speed pumps), 12 basic condensation pumps (all are frequency-conversion pumps), 6 supplementary water pumps, 2 deaeration pumps, 2 medication pumps, 1 softening water supply pipeline pump and 1 tap water pipeline pump). During the heating season, the flow rate of circulating water in the heating network t/h, t/h, pressure 1.38/1.27MPa, and the temperature of water supply and return in the design of the heating network are 8000t/h, 8000t/h, 6500t/h and 130/70MPa. The actual maximum heating flow is 7500-8200T, pressure is 1.38MPa, supply and return water temperature is 96/50°C and #3 network is 84/49°C.

3. Test conditions

During the test, the following nine working conditions were determined according to the analysis of the heating conditions of the whole plant and the heating capacity of 9 unit, see Table 1 for details.

| Numble | Industrial steam extraction (t/h) | Heating and steam extraction (t/h) | Load (MW) |
|--------|----------------------------------|----------------------------------|-----------|
| 1      | 0                                | 0                                | 130       |
| 2      | 0                                | 99                               | 126       |
| 3      | 60                               | 0                                | 124       |
| 4      | 0                                | 99                               | 80        |
| 5      | 60                               | 210                              | 105       |
| 6      | 0                                | 210                              | 108       |
| 7      | 0                                | 210                              | 111       |
| 8      | 60                               | 0                                | 75        |
| 9      | 0                                | 0                                | 80        |

4. Field test

Under this condition, the industrial exhaust flow rate is 0 t/h and the heating exhaust flow rate is 0 t/h. Turn off the heating and steam extraction and industrial steam extraction control valves, determine the heating and steam extraction and industrial steam extraction flow of the unit is 0 t/h, and gradually increase the main steam flow to 488 t/h, which has reached the maximum evaporation of the boiler. The average active power of the generator is 129.84 MW.
Under this condition, the maximum electric load test of industrial steam extraction flow rate is 0 t/h and rated heating steam extraction flow rate is 99 t/h. On the basis of working condition 1, keep the maximum load of the boiler unchanged, open the heating steam extraction regulating valve, gradually increase the heating steam extraction flow to the rated heating steam extraction flow. During the test period, the average industrial steam extraction flow is 0 t/h, the average heating steam extraction flow is 98.19 t/h, and the average active power of generator is 126.38 MW. 

This working condition is rated industrial steam extraction flow (60t/h), heating steam extraction flow is 0 t/h maximum electric load test. Close the unit's heating exhaust regulating valve and determine the heating exhaust flow rate to be 0 t/h. Because the total industrial exhaust flow rate of the whole plant is lower than the rated industrial exhaust flow rate of the unit, the whole plant's industrial exhaust steam is supplied by the unit, and gradually open the unit's industrial exhaust regulating valve, at the same time close the industrial exhaust regulating valves of # 3 and # 4 units, and the unit's industrial exhaust steam is supplied by the unit. The flow rate gradually increases to the maximum demand of current users about 49 t/h, and the boiler load increases to the maximum. At this time, the main steam flow rate is 489 t/h. During the test period, the average industrial steam extraction flow rate of the unit is 49.03 t/h, the average heating steam extraction flow rate is 0 t/h, and the average active power of the generator is 123.91 MW. 

This condition is the lowest electric load test of industrial steam extraction flow rate of 0 t/h and rated heating steam extraction flow rate of 99 t/h. Close the industrial steam extraction regulating valve of the unit and determine the industrial steam extraction flow rate is 0 t/h; open the heating steam extraction regulating valve, gradually increase the heating steam extraction flow to the rated heating steam extraction flow rate; gradually reduce the unit load to about 80 MW, at this time, the left reheat steam temperature and the right reheat steam temperature are 520 C, 515 C, respectively. The operating regulations stipulate that reheat steam temperature should be alarmed as low as 520 C to reach the limit of minimum electric load. The average industrial steam extraction flow of the unit is 0 t/h, the average heating steam extraction flow is 101.85 t/h, and the average active power of the generator is 79.46 MW. 

The original plan was to test the rated industrial steam extraction capacity and maximum heating steam extraction capacity with the lowest load. When the butterfly valve of low-pressure cylinder was gradually turned off during the test, the exhaust temperature of low-pressure cylinder gradually increased. Although the exhaust temperature did not reach the alarm value (83 C), the X-direction relative vibration value of unit 2 axle gradually increased from 50 m to about 150 m, and the test was carried out. Stop and start again. Based on this situation, the butterfly valve of low-pressure cylinder is gradually closed for hours, and the exhaust temperature of low-pressure cylinder of the unit does not rise. 

This working condition is rated industrial extraction flow (60t/h), maximum heating extraction flow (210t/h) and minimum electric load test. First, the industrial extraction control valves of units 3 and 4 are gradually closed and the industrial extraction control valves of units 4 are opened. All industrial extraction steam of the plant is supplied by the unit, and the industrial extraction flow is gradually increased to about 54t/h. When the temperature of exhaust steam in low pressure cylinder begins to rise, the heating exhaust steam flow rate is about 194 t/h, the main steam flow rate is about 490 t/h, and the main steam flow rate has reached the maximum boiler evaporation rate. At the same time, when the unit load and the opening of butterfly valve in low pressure cylinder begin to rise, the heating exhaust steam flow rate is about 490 t/h. Under this condition, the maximum electric load test shows that the heating extraction steam flow reaches the maximum current extraction steam flow. During the test, the average industrial extraction steam flow of the unit is 54.47 t/h, the average heating extraction steam flow is 193.52 t/h, and the average active power of the generator is 105.77 MW. 

This condition is the lowest electric load test of industrial extraction steam flow rate of 0 t/h, maximum heating extraction steam flow rate of 210 t/h. On the basis of working condition 5, keep the unit heating extraction steam flow rate of about 194 t/h, close the industrial extraction regulating valve of the unit, and the whole plant industrial extraction steam is provided by # 3 and # 4 units. Gradually reduce the unit load and low-pressure cylinder intake butterfly valve opening, maintain the heating and
extraction steam flow unchanged. When the low-pressure cylinder intake butterfly valve closes down to the low-pressure cylinder exhaust temperature starts to rise, the limit condition of this working condition is reached. During the test period, the average industrial exhaust flow of the unit is 0 t/h, the average heating exhaust flow is 198.12 t/h, and the average active power of the generator is 108.68 MW.

Under this working condition, the operation parameters of the unit are basically normal, the boiler has not found any abnormal conditions such as overheating, coking, large area slagging, and the auxiliary machines of the unit are working normally; the denitrification device, dust removal device and desulfurization device are working normally, and the environmental protection data are qualified.

This condition is the maximum electric load test of industrial extraction flow rate of 0 t/h and maximum heating extraction flow rate of 210 t/h. On the basis of working condition 6, keep the industrial steam extraction flow and heating steam extraction flow unchanged, gradually increase the main steam flow to the maximum evaporation of the boiler. During the test period, the average industrial steam extraction flow of the unit is 0 t/h, the average heating steam extraction flow is 191.78 t/h, and the average active power of the generator is 110.81 MW.

The working conditions are rated industrial exhaust flow (60 t/h) and minimum electric load test of heating exhaust flow (0 t/h). Firstly, confirm the unit heating extraction steam flow rate is 0 t/h, then gradually close the industrial extraction steam regulating valves of #3 and #4 units, open the industrial extraction steam regulating valves of the unit, all the industrial extraction steam of the plant is supplied by the unit, and the unit industrial extraction steam flow rate gradually increases to about 54 t/h; gradually reduce the unit load to about 75 MW, at this time the left side is reheated. The steam temperature and the right middle pressure reheat steam temperature are 526 and 517 ℃ respectively, reaching the alarm value (520 ℃) in the operation regulation, triggering the limited conditions under this condition and stopping the power-reducing load. During the test period, the average industrial steam extraction flow of the unit is 54.56 t/h, the average heating steam extraction flow is 0 t/h, and the average active power of the generator is 74.51 MW.

This condition is the lowest electric load test with industrial extraction flow rate of 0 t/h and heating extraction flow rate of 0 t/h. On the basis of working condition 8, close the industrial steam extraction regulating valve of the unit, determine the flow rate of heating steam extraction and industrial steam extraction is 0 t/h, and gradually reduce the unit load to about 80 MW. At this time, the left reheat steam temperature and the right medium pressure reheat steam temperature are 520 and 512 ℃, respectively, reaching the alarm value (520 ℃) in the operation regulation and triggering. Under the limited conditions under this condition, the power load is stopped. During the test period, the average industrial steam extraction flow of the unit is 0 t/h, the average heating steam extraction flow is 0 t/h, and the average active power of the generator is 80.97 MW.

5. Conclusion
When the industrial exhaust flow rate is 0 t/h and the heating exhaust flow rate is 0 t/h, the electric load adjustment range of the test unit is 80.97 MW ~ 129.84 MW. When the industrial extraction flow is 0 t/h and the heating extraction flow is 100.02 t/h, the electric load adjustment range is 79.46 MW ~ 126.38 MW. When the industrial extraction flow is 0 t/h and the heating extraction flow is 194.96 t/h, the range of electric load adjustment is 108.68 MW ~ 110.81 MW. When the industrial extraction flow rate is 51.79 t/h and the heating extraction flow rate is 0 t/h, the electric load adjustment range is 74.51 MW ~ 123.91 MW. When the industrial extraction flow rate is 54.47 t/h and the heating extraction flow rate is 193.53 t/h, the electric load is 105.77 MW and there is no adjustment space. The load range of 150 MW double-pumped high back pressure units is shown in Table 2.
Table 2. Load interval of 150 MW double-pumping high back pressure unit

| Number | Industrial steam extraction (t/h) | Heating and steam extraction (t/h) | Load (MW) | Maximum | Minimum |
|--------|----------------------------------|-----------------------------------|----------|---------|---------|
| 1      | 0                                | 0                                 | 129.84   | 80.97   |
| 2      | 0                                | 100.0184                          | 126.38   | 79.46   |
| 3      | 0                                | 194.9558                          | 110.81   | 108.68  |
| 4      | 51.7949                          | 0                                 | 123.91   | 74.51   |
| 5      | 54.4689                          | 193.5344                          | 105.77   | 105.77  |

Generally speaking, the high back pressure operation heating mode is suitable for the heating system with low return water temperature, large water quantity and large heat supply. However, under the condition of high back pressure, the low pressure cylinder may be overheated, which results in the limitation of minimum load and the decline of peak shaving performance. The main reason is that the last stage blade has the phenomenon of bleeding under the condition of small flow rate and high back pressure. Relevant research shows that the bleeding on the last stage blade becomes more and more serious with the increase of back pressure under the same mass flow rate condition. The smaller the flow rate in the stage, the larger the bleeding area under the same back pressure [5]. For units revamped with low-pressure rotors and high back pressure, all the heating steam works through steam turbines, resulting in strong coupling between heat supply and power generation. The load regulation of such units is very poor, and they basically do not have peak shaving capacity. The peak shaving capacity of high back pressure heat supply unit is between 4.8MW and 8.8MW (1.5%~2.7%) under different steam flow rate. The peak-shaving capacity of high back pressure heat supply units is between 17 MW and 31 MW (3.5%-6.5%) under different generator power of steam turbines [6]. Pure high back pressure heat supply units generally have strong heating capacity, but the peak shaving capacity of double-pumping heat supply units is significantly enhanced after high back pressure transformation. In normal operation, pure exhaust steam operation is considered from the economic point of view. When peak regulation is needed, the operation of pumping steam to reduce load can be adjusted to alleviate peak regulation pressure.

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