Experimental Study on Peak-shaving Ability of a 330MW Thermal Power Unit in Heating State

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Abstract. The peak-shaving capacity of thermal power units is affected by the amount of steam extracted, so the design of the working condition diagram of heat supply cannot accurately reflect the actual peak-shaving performance of units. In order to solve the above problems, this paper takes a 330MW thermal power unit as an example, gets the actual peak-shaving upper and lower limits of the unit under different extraction flow rates through peak-shaving capacity test, and compares them with the design heating working diagram, and analyses the reasons for the deviation of the actual peak-shaving capacity and design value, so as to provide reference for the operation and dispatch of the power plant and help power plants to better participate in peak shaving of ancillary services.

1. Introduction

In recent years, with the increasing environmental protection and pressure reduction of coal burning, Shandong Province has intensified the development of new energy and UHV external power entering. At present, the installed capacity of photovoltaic and wind power in Shandong Province has both exceeded 10 million kilowatts. By the end of 2018, they are 13.61 million kilowatts and 11.46 million kilowatts, respectively. Development Planning of New Energy Industry in Shandong Province (2018-2028) issued by Shandong Provincial People's Government points out that the installed capacity of new energy power generation will reach about 44 million kilowatts by 2022 which accounts for about 30% of the installed capacity of the whole province and it will reach about 75 million kilowatts by 2028 which accounts for about 40% of the installed capacity of the whole province.

In terms of UHV external power entering to Shandong, Ximeng--Shandong UHV AC was put into operation in 2016, Yuheng--Weifang UHV AC, Shanghai miao--Linyi UHV DC and Zalute--Qingzhou UHV DC were put into operation in 2017. In 2018, Shandong Power Grid accepted 71.956 billion kilowatt-hours of external electricity which accounts for 15% of the total power consumption of the whole network; In July 2019, Shandong Power Grid accepted 20 million kilowatt-hours of external electricity for the first time, and it is expected that Shandong Power Grid will receive about 35 million kilowatt-hours of external electricity by 2020 which accounts for 22% of the installed capacity of whole province.

New energy and external electricity greatly reduce the grid space of thermal power. The proportion of thermal power generation and utilization hours have declined year by year so that profit can't be maintained solely by power generation. In the future, thermal power must seek transformation and
participate more in auxiliary service of power grid peak shaving to obtain compensation for peak shaving income.

The proportion of thermal power units in Shandong power grid has exceeded 76%, the peak-shaving ability of thermal power units in heating state is different from that in pure condensation state which is not fixed, but a dynamic change with heating quantity. Heat supply changes with the weather, and the peak-shaving capacity of the unit also changes. So that, in order to participate in peak shaving of auxiliary services, the unit must find out the peak-shaving capacity under the heating condition.

Peak-shaving ability of thermal power unit under heating condition is usually obtained by designing heating working condition diagram which can not accurately reflect it from two aspects. First, for the protection of steam turbines, the design heat-supply working condition diagrams issued by steam turbine manufacturers are relatively conservative, the operating range is narrow, so that the unit may break through the design condition in actual operation; Secondly, the design of heat supply working diagram reflects the peak-shaving capacity of the unit under rated parameters. The actual operating parameters of the unit are often quite different from the rated values, so the actual peak-shaving capacity is also quite different from the design values.

Peak shaving capacity test under extraction condition overcomes the above drawbacks of heating working diagram and is the most effective means to find out the peak shaving capacity of units under heating condition. This paper takes a 330MW thermal power unit as an example, gets the actual peak-shaving upper and lower limits of the unit under different extraction flow rates through peak-shaving capacity test, and compares them with the design heating working diagram , and analyses the reasons for the deviation of the actual peak-shaving capacity and design value, so as to provide reference for the operation and dispatch of the power plant and help power plants to better participate in peak shaving of ancillary services.

2. Overview of unit heating
The general situation of a 330MW thermal power unit is as follows: the type of steam turbine is C330-16.7/0.8/538/538, subcritical, primary reheat, high and medium pressure cylinder closure, double cylinder, double exhaust, single axis, extraction condensation type. The unit undertakes both industrial steam extraction and heating steam extraction. Industrial steam extraction is high-exhaust non-adjustable extraction. The designed extraction capacity is 50 t/h and the actual extraction capacity is 20 t/h; Heating steam extraction capacity is adjusted by middle exhaust, rated steam extraction pressure is 0.8 MPa, maximum designed steam extraction capacity is 300 t/h, rated steam extraction capacity is 280 t/h, actual maximum steam extraction capacity is 240 t/h, average steam extraction capacity is 180 t/h in the previous year.

The main limiting factors affecting the peak shaving capacity of units in actual operation are as follows:
1) Boiler maximum evaporation limit: the maximum steam intake of the unit can not exceed the maximum evaporation of the boiler 1025 t/h;
2) Medium exhaust temperature limitation: According to the operation specifications, the exhaust temperature of the medium pressure cylinder should not exceed 388 C, and the main steam flow should be greater than 620 t/h after the steam extraction is put into operation, otherwise the exhaust temperature of the medium pressure cylinder will exceed the limit value of 388 C.
3) Minimum intake limit of low-pressure cylinder: In order to prevent blowout of last stage blade due to too small exhaust volume flow, the minimum cooling flow of low-pressure cylinder of unit under rated back pressure is 100t/h. Because the flow of low-pressure cylinder can not be measured in actual operation, the intake pressure of low-pressure cylinder can not be lower than 0.1MPa by monitoring the intake pressure measuring point of low-pressure cylinder.
4) Medium exhaust pressure limit: In order to ensure the safety and reliability of the medium pressure cylinder blades, the exhaust pressure of the medium pressure cylinder should not be less than 0.8 MPa when adjusting the steam extraction input. If it is needed to extract steam under this pressure, it can be satisfied by adjusting the throttle of the regulating valve on the steam extraction pipeline. The low alarm
value of extraction pressure is 0.75 MPa and the low action value of extraction pressure is 0.7 MPa. When the extraction pressure is low to the alarm value, measures such as increasing the steam intake of the unit should be taken to increase the middle exhaust pressure. If the extraction pressure continues to decrease to the action value, the extraction steam will be automatically disassembled. The design heating working diagram of unit is shown in figure 1.

![Fig.1 Design heating working diagram of unit](image)

The upper and lower limits of peak shaving for unit under typical extraction conditions according to the design heat supply working condition diagram are shown in Table 1.

| extraction conditions | upper limits of peak shaving (MW) | lower limits of peak shaving (MW) |
|-----------------------|----------------------------------|----------------------------------|
| industrial steam extraction 50t/h heating steam extraction 240t/h | 260 | 131 |
| industrial steam extraction 50t/h heating steam extraction 200t/h | 270 | 142 |
| industrial steam extraction 50t/h heating steam extraction 165t/h | 278 | 151 |

3. Test conditions and process
According to the typical coupling condition of heating and industrial steam extraction in the daily operation of the unit, eight test conditions are determined. The specific test conditions and test process are as follows:

1) Condition 1: industrial extraction 20t/h, heating extraction 240t/h, test the maximum electrical load;
   Test process: take the industrial steam extraction flow to 20t/h, heating steam extraction flow to 240t/h, and gradually increase the main steam flow of the unit. When the main steam flow reaches 1025t/h, the boiler evaporation reaches the maximum. Keep the working condition stable and record for two hours. During the test, the average electric load is 264.967MW, and the limiting factor of the output is the maximum evaporation capacity of the boiler. Under this condition, the operation parameters of the unit are normal; the boiler heating surface has not found overheating; the auxiliary machine works normally; the environmental protection device works normally, and the environmental protection index is qualified.

2) Condition 2: industrial extraction 20t/h, heating extraction 240t/h, test the minimum electrical load;
   Test process: on the basis of condition 1, keep the industrial extraction flow constant at 20t/h, gradually reduce the main steam flow of the unit, keep the heating extraction flow constant at 240t/h,
and gradually turn down the low-pressure cylinder inlet butterfly valve. When the low-pressure cylinder inlet butterfly valve reaches the minimum limit value, stop reducing the load, keep the working condition stable, and record for two hours. During the test, the average electric load of the unit is 191.172MW, and the limiting factor of the unit output is the minimum steam inlet flow of the low pressure cylinder. Under this condition, the operation parameters of the unit are normal; the boiler heating surface has not found overheating; the auxiliary machine works normally; the environmental protection device works normally, and the environmental protection index is qualified.

3) Condition 3: cut off the industrial steam extraction, keep the heating extraction flow constant at 240t/h, test the maximum electrical load;

Test process: cut off the industrial steam extraction flow, maintain the heating steam extraction flow of 240t/h, and gradually increase the main steam flow of the unit. When the main steam flow reaches 1025t/h, the boiler evaporation reaches the maximum, and keep the working condition stable, and record for two hours. During the test, the average electric load of the unit is 277.463MW, and the limiting factor of the unit output is the maximum evaporation capacity of the boiler. Under this condition, the operation parameters of the unit are normal; the boiler heating surface has not found overheating; the auxiliary machine works normally; the environmental protection device works normally, and the environmental protection index is qualified.

4) Condition 4: cut off the industrial steam extraction, keep the heating extraction flow constant at 240t/h, test the minimum electrical load;

Test process: on the basis of condition 3, keep the industrial extraction flow constant at 0t/h, gradually reduce the main steam flow of the unit, keep the heating extraction flow constant at 240t/h, and gradually turn down the low-pressure cylinder inlet butterfly. When the inlet butterfly valve of the low-pressure cylinder reaches the minimum limit value, stop reducing the load, keep the working condition stable, and record for two hours. During the test, the average electric load of the unit is 175.014MW, and the limiting factor of the unit output is the minimum steam inlet flow of the low pressure cylinder. Under this condition, the operation parameters of the unit are normal; the boiler heating surface has not found overheating; the auxiliary machine works normally; the environmental protection device works normally, and the environmental protection index is qualified.

5) Condition 5: cut off the industrial steam extraction, keep the heating extraction flow constant at 180t/h, test the maximum electrical load;

Test process: cut off the industrial steam extraction flow, maintain the heating steam extraction flow of 180t/h, and gradually increase the main steam flow of the unit. When the main steam flow reaches 1025t/h, the boiler evaporation reaches the maximum, keep the working condition stable, and record for two hours. During the test, the average electric load of the unit is 289.875MW, and the limiting factor of the unit output is the maximum evaporation capacity of the boiler. Under this condition, the operation parameters of the unit are normal; the boiler heating surface has not found overheating; the auxiliary machine works normally; the environmental protection device works normally, and the environmental protection index is qualified.

6) Condition 6: cut off the industrial steam extraction, keep the heating extraction flow constant at 180t/h, test the minimum electrical load;

Test process: on the basis of condition 5, gradually reduce the main steam flow of the unit, keep the heating steam extraction flow unchanged at 180t/h, and gradually turn down the low-pressure cylinder inlet butterfly. When the inlet butterfly valve of the low-pressure cylinder reaches the minimum limit value, stop reducing the load, keep the condition stable, and record for two hours. During the test, the average electric load of the unit is 159.978MW, and the limiting factor of the unit output is the minimum steam inlet flow of the low pressure cylinder. Under this condition, the operation parameters of the unit are normal; the boiler heating surface has not found overheating; the auxiliary machine works normally; the environmental protection device works normally, and the environmental protection index is qualified.

7) Condition 7: cut off the heating steam extraction, keep the industrial steam extraction at 20t/h, and test the maximum electrical load;
Test process: keep the industrial steam extraction at 20t/h, gradually reduce the heating steam extraction flow by turning down the steam extraction butterfly valve, and gradually pour the heating steam extraction to the unit. In the process, it is found that the extraction stop valve is jammed and cannot be opened. The test cannot continue due to equipment reasons.

8) Condition 7: cut off the heating steam extraction, keep the industrial steam extraction at 20t/h, and test the minimum electrical load;
Test process: the test was not carried out due to the lack of conditions, the reason is the same as condition 7.

4. Test results and analysis
Peak-shaving capability test upper and lower limits of unit peak-shaving under different extraction conditions are shown in Table 2.

**Tab. 2** Peak-shaving capability test upper and lower limits of unit peak-shaving under different extraction conditions

| extraction conditions | upper limits of peak shaving (MW) | lower limits of peak shaving (MW) |
|-----------------------|----------------------------------|---------------------------------|
| industrial steam extraction 20t/h heating steam extraction 240t/h | 264.967 | 191.172 |
| industrial steam extraction 0t/h heating steam extraction 240t/h | 277.463 | 175.014 |
| industrial steam extraction 0t/h heating steam extraction 180t/h | 289.875 | 159.978 |

In Table 1, upper and lower limits of peak-shaving under typical extraction conditions are obtained according to the design heating working condition diagram of the unit. The industrial extraction capacity of the unit under the design working condition is 50t/h, while the actual industrial extraction capacity in the peak-shaving test is 20t/h and 0t/h. In order to facilitate the comparison between the test and the design, the industrial extraction capacity is modified from the design value to the actual value. Modification of the upper limit of peak regulation by industrial extraction should be calculate with formula (1):

\[ P'_s = P_s + (G_g - G'_g)(h_g + h_{hrh} - h_{crh} - h_{ex})/3600 \]  

Modification of the lower limit of peak regulation by industrial extraction should be calculate with formula (2):

\[ P'_x = P_x - (G_g - G'_g)(h_z - h_g)/3600 \]  

Where: \( P_s \) and \( P_x \) are respectively the upper and lower limit of the design peak regulation in the heating working condition diagram, unit is MW; \( P'_s \) and \( P'_x \) are respectively the upper and lower limit of the peak regulation after the industrial extraction is corrected to the actual value, unit is MW; \( G_g \) is the design industrial extraction flow, unit is t/h; \( G'_g \) is the actual industrial extraction flow, unit is t/h; \( h_z \) is the main steam enthalpy, unit is kJ/kg; \( h_g \) is the industrial extraction enthalpy, unit is kJ/kg; \( h_{hrh} \) is the reheat steam enthalpy, unit is kJ/kg; \( h_{crh} \) is the reheat steam enthalpy, unit is kJ/kg; \( h_{ex} \) is the exhaust enthalpy of the low-pressure cylinder, unit is KJ/kg.

In test condition 5 and 6, the heating steam extraction is 180t/h, but there is no typical working condition of 180t/h in the design heating working condition diagram. As shown in formula (3), the
design electric load under the heating air extraction volume of 180t/h is calculated by interpolation method.

\[ P = P_i + \frac{P_{i+1} - P_i}{Q_{i+1} - Q_i} (Q - Q_i) \]  

(3)

Where: \( P \) is the electrical load under the actual extraction capacity, unit is MW; \( P_i \) is the corresponding electrical load under the group \( i \) typical extraction capacity in the heating condition diagram, unit is MW; \( P_{i+1} \) is the corresponding electrical load under the group \( i+1 \) Typical extraction capacity in the heating condition diagram, unit is MW; \( Q \) is the actual extraction capacity, unit is t/h; \( Q_i \) is the typical extraction capacity of group \( i \) in the heating working condition diagram, unit is t/h; \( Q_{i+1} \) is the typical extraction capacity of group \( i+1 \) in the heating working condition diagram, unit is t/h.

Using formula (1), (2) and (3), the design values of the upper and lower limits of peak regulation for each extraction condition in Table 2 can be calculated. Comparison of actual and design values of peak shaving upper and lower limits of unit under different extraction conditions is shown in Table 3.

**Tab. 3 Comparison of actual and design values of peak shaving upper and lower limits of unit under different extraction conditions**

| extraction conditions                   | upper limits of peak shaving (MW) | lower limits of peak shaving (MW) |
|----------------------------------------|-----------------------------------|----------------------------------|
|                                        | actual value | design value | actual value | design value |
| industrial steam extraction 20t/h      | 264.967      | 269.838      | 191.172      | 127.858      |
| heating steam extraction 240t/h        |               |              |               |              |
| industrial steam extraction 0t/h       | 277.463      | 276.399      | 175.014      | 122.622      |
| heating steam extraction 240t/h        |               |              |               |              |
| industrial steam extraction 0t/h       | 289.875      | 290.970      | 159.978      | 138.765      |
| heating steam extraction 180t/h        |               |              |               |              |

It can be seen from table 3 that under the three extraction conditions of industrial extraction 20t/h and heating extraction 240t/h; industrial extraction 0t/h and heating extraction 240t/h; industrial extraction 0t/h and heating extraction 180t/h, the deviation between the actual value of the upper peak regulation limit and the design value of the unit is not large, basically reaching the design value. The lower peak regulation limit of the unit does not reach the design value, and the actual value of the lower peak regulation limit of the three extraction conditions are both higher than the design value, the difference values are 63.314MW, 52.392MW and 21.213MW. According to the analysis, there are two main reasons for the lower limit of unit peak load regulation not reaching the design value:

1) The thermal power company has not built a relay booster pump station outside the plant according to the design requirements. The pressure required for the heat supply network circulation outside the plant is provided by the heat supply network circulation pump in the initial heat supply station. In order to maintain the circulation pressure of the external network, the heat supply network circulation pump needs a larger pressure head than designed. The heat supply network circulation pump is driven by a small turbine which steam source comes from the middle exhaust. During the minimum electrical load test of each extraction condition, due to the low electrical load the middle discharge pressure is too low to maintain the pressure head required by the heat supply network circulating pump. When the inlet valve of the small turbine has been fully opened, the main steam flow shall be increased to increase the middle exhaust pressure, so as to maintain the high speed of the small turbine. Therefore, the actual main steam flow of the unit is higher than the design value under each low load condition, and the work
of the high and medium pressure cylinder is increased, resulting in the rise of the minimum electrical load.

2) The minimum electrical load test of each extraction condition stop load reduction when the inlet butterfly valve of low-pressure cylinder reaches the limit value. In the actual operation, the limit value of the inlet butterfly valve of low-pressure cylinder is set too high so that the actual inlet steam volume of low-pressure cylinder far exceeds the limit line of the minimum inlet steam volume of low-pressure cylinder 100t/h which leading to the rise of the minimum electrical load.

For the above two reasons, the following suggestions are given:

3) The heat supply network circulating pump can not operate outside the designed head for a long time. The first reason is that it is easy to cause equipment damage and shorten the pump life; the second reason is that it is easy to increase the extraction steam of the unit, resulting in the increase of heat consumption and the decrease of the capacity with low load. The power plant shall require the heat supply company to build the relay booster pump station as soon as possible.

4) According to the steam inlet pressure of the low-pressure cylinder, recheck the limit of the steam inlet butterfly valve of the low-pressure cylinder, and try to reduce the limit value of the butterfly valve of the low-pressure cylinder.

5. Conclusion

In view of the problem that the design heat supply working condition chart of the thermal power unit can not accurately reflect the actual peak load regulation capacity of the unit, this paper takes a 330MW thermal power unit as an example, proposes to obtain the real peak load regulation capacity data of the unit under different extraction flow through the test, makes a specific introduction to the test conditions and the test process, and compares the actual peak load regulation capacity value of the unit obtained from the test with the design value, and finds that Under different extraction conditions, the maximum electric load of the unit basically reaches the design value, while the minimum electric load is much higher than the design value. Then, the reasons for the decrease of the capacity of the unit with low load are analyzed and the targeted suggestions are given to help the power plant tap the potential of low load peak regulation and better participate in peak regulation auxiliary services.

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