Research on electric load adjustment ability of different types of heat supply units

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Abstract. With the development of renewable energy and the rapid growth of thermal load, due to the influence of the mode of "determining power by heat", the power grid dispatching in heating season can not accurately adjust the unit load, and the peak load regulation capacity of power grid is limited. Through the load capacity test of cogeneration units in heating season, the adjustment range and limiting factors of different types of units are obtained, which can be used as reference for power generation enterprises and power grid dispatching operation.

1. Background
In the northern region, especially in the "Three North" areas, urban cogeneration units account for a large proportion. In the situation of increasing renewable energy consumption, with the increasing demand for heating, the rapid development of renewable energy and the introduction of peak regulation compensation measures in various regions [1], it is bound to break the operation mode of "determining power by heat" of cogeneration units [2], so as to tap the peak shaving potential of heating units. Shandong new energy industry development plan (2018-2028) issued by the people's Government of Shandong Province points out that by 2022, the installed capacity of new energy power generation will reach about 44 million kilowatts, accounting for about 30% of the installed capacity of the whole province; by 2028, the installed capacity of new energy power generation will reach about 75 million kilowatts, accounting for about 40% of the installed capacity of the whole province. At present, Shandong power grid has no hydropower and gas turbine, only 1 million pumped storage energy, and peak shaving mainly relies on thermal power; the proportion of thermal power units in heating season is more than 76%, under the premise of ensuring people's livelihood, the peak regulation capacity of power grid in heating season [3] is seriously restricted. To sum up, in order to increase the stability and reliability of peak load regulation in Shandong power grid, it is necessary to find out the actual load carrying capacity of heating units in the whole province.

2. Load test of cogeneration unit
10 heating units are selected for field test in the heating season from 2019 to 2020. The actual maximum and minimum electrical loads of these units under different working conditions are measured, and their limiting factors are obtained. For the convenience of distinguishing and explaining, 11 test units are set according to 1, 2, 3⋯⋯10.
2.1. High back pressure heating unit

| Steam Turbine Units | type | Rated capacity (Before transformation /MW) | Industrial Extraction Steam (t/h) | Heating and steam extraction (t/h) | Load interval (MW) |
|-------------------|------|-------------------------------------------|----------------------------------|-----------------------------------|-------------------|
| #1                | High back pressure heating unit  | 125 / / 65                        | /                                | /                                | 65～102            |
| #2                | High back pressure heating unit  | 135 / / 60                        | /                                | /                                | 60～120            |
| #3                | Single extraction + High back pressure | 145 / / 0                         | 0                                | 40                               | 80 85～110         |
|                   |                                |                            |                                  |                                  | 80 90～105         |

The load ranges of 4 high back pressure units [4] under different working conditions in heating season are shown in Table 1.

During the load increasing process of unit 1, the differential pressure of the hollow preheater increased, and the fan limited the maximum electrical load of the unit; the minimum electrical load was limited by the limit value of the power circuit in the plant, which did not reach the minimum stable combustion load of the boiler.

The maximum electric load of unit 2 is the maximum evaporation capacity of boiler, and the minimum electrical load is limited by the minimum stable combustion load.

The maximum electric load of unit 3 is limited by the maximum evaporation of boiler, and the minimum electric load is limited by industrial steam supply pressure and heating heat flow. The power plant where unit 3 is located adopts the combined heating mode of the whole plant, and the heating system is highly coupled; the industrial steam and residential heating steam are led out from a main pipe and cannot be adjusted independently, and the industrial steam extraction parameters are required to be no less than 0.6MPa and 260℃; in order to ensure the heating quality, the instantaneous heat flow of heating and heating in the whole plant shall not be less than 900GJ/h. The extraction flow rate is 80 t/h test with minimum electrical load, the electric load is adjusted to 85MW according to the plan. In order to meet the heating demand of the whole plant, the other two units in the plant can not maintain 73MW load operation according to the dispatching instructions, so the power plant applies for over limit operation for 2 hours. After that, the heating demand of the power plant can be met. Therefore, under this operation mode, the minimum electrical load of the unit is 85MW, but the electrical load of the other two units in the plant should be maintained Not less than 90MW.

2.2. Heat supply unit after low pressure cylinder zero output transformation

After low pressure cylinder zero output transformation, the heat supply unit is divided into two parts: the smooth shaft heat supply unit and the cylinder cutting heat supply unit. The test results are shown in Table 2.
Table 2. Load of heat supply unit under different conditions after zero output retrofit of low pressure cylinder

| Steam Turbine Units | type | Rated capacity (Before transformation /MW) | Industrial Extraction Steam (t/h) | Heating and steam extraction (t/h) | Load interval (MW) |
|---------------------|------|------------------------------------------|----------------------------------|-----------------------------------|-------------------|
| #4 Optical axis transformation | 225 | /                                       | 346, 113                         | 283, 91                           | 259, 78           |
| #5 Do not cut cylinder | 350 | /                                       | 218, 328                         | 218, 154                          | 490, 264          |
| Cutting cylinder    |      | /                                       | 374, 130                         | 488, 201                          | 611, 256          |

2.2.1. Reforming heating unit with optical shaft. Unit 4 is a heat supply unit after optical shaft transformation [5]. Due to the limitation of local temperature and heating area of the power plant, the load carrying capacity of the unit is limited. In order to find out the upper and lower limits of unit output and the corresponding curves of main steam and extraction steam flow, three test conditions are determined according to the typical working conditions of unit design heating condition diagram. Condition 1: under 110MW condition, the extraction pressure (middle exhaust pressure) is close to the rated value of 0.16MPa mpa by adjusting the heating butterfly valve, and the main steam flow and external extraction steam flow of the unit are measured; when the main steam flow is 486t/h, the water supply temperature of the heat supply network reaches the maximum limit value (120℃), and the unit load cannot continue to increase. Therefore, this working condition is considered as the current maximum electrical load condition of the unit. Condition 2: under 90MW condition, adjust the extraction pressure to close to the rated value of 0.16MPa, and measure the main steam flow and external extraction steam flow of the unit. Condition 3: under 77MW condition, adjust the extraction pressure to close to the rated value of 0.16MPa, and measure the main steam flow and external extraction steam flow of the unit; when the main steam flow is 357t/h, it is lower than the design minimum stable combustion flow of the boiler 374t/h, and the unit load will no longer be reduced. Therefore, this working condition is considered as the lowest electrical load condition of the unit.

2.2.2. Reforming heating unit by cutting cylinder. Unit 5 is a low-pressure cylinder cut-off [6] retrofitted unit. Considering that there are two operation states of the unit, namely, no cylinder cutting and cylinder cutting, the tests are carried out under the two operating conditions.

Conditions 1 and 2: under the condition of no cylinder cutting, the maximum and minimum electric load of the unit is measured when the heat supply and extraction steam flow reaches the average value of 220t/h in the previous year; due to the installation of denitrification, desulfurization, low-cost and other facilities in the flue of the unit in the later stage of the unit, the induced draft fan deviates from the design operation condition, and when the pressure rise exceeds 7500Pa, it is easy to cause surge. According to the relevant provisions of the power plant operation, in order to ensure the safe operation of the unit, it is necessary to ensure the safe operation of the, the pressure rise of induced draft fan is controlled at about 7500Pa. In condition 1, when the main steam flow rises to 1060t/h, the pressure rise of induced draft fans a and B reaches 7500Pa, and the unit output will not continue to increase; in condition 2, the minimum electrical load is limited to 50% of the boiler load. Since the cylinder cutting transformation of unit 5 has been completed, the opening limit of medium and low pressure connecting pipe butterfly valve is no longer set, and the pressure behind the valve is displayed as 0 as the judgment of the minimum cooling flow of the low pressure cylinder The opening of the pressure communicating pipe butterfly valve is 20.39%, the pressure behind the valve is 0.05Mpa, and the pressure behind the valve is greater than 0, which proves that the cooling flow of the low-pressure cylinder has not been reduced to the
minimum, and the unit has the ability to continue to reduce the load. Condition 3: under the condition of no cylinder cutting, when the heat supply steam extraction flow reaches the maximum value of 490t/h, the unit electrical load is measured; during the test, the pressure rise of induced draft fans a and B reaches 7500Pa, the opening of medium and low pressure connecting pipe butterfly valve is 13.19%, and the pressure behind the valve is reduced to 0MPa, which has reached the minimum cooling flow of low pressure cylinder, and the butterfly valve opening is no longer reduced.

Under the condition of cylinder cut-off, three working conditions were tested, respectively, when the unit's minimum extraction flow (condition 4), heating extraction flow 490t/h (condition 5), and heating extraction flow reaching the maximum value of 610t/h (condition 6), the unit electrical load was measured. Condition 4: when the main steam flow is about 600t/h, start to adjust the heating and extraction steam quick closing control valve, confirm that the inlet steam pressure of the low pressure cylinder is not less than 0.09MPa (absolute pressure), quickly close the butterfly valve opening of the medium and low pressure connecting pipe to 0, adjust the opening of the steam regulating valve of the bypass of the low pressure cylinder, control the cooling steam flow of the low pressure cylinder about 20t/h, complete the cylinder cutting of the low pressure cylinder, and continue to reduce the boiler load to 50% The boiler load, at this time, the main steam flow is 524t/h, the heat extraction flow is 374t/h, and the active power of the generator is 130MW; continue to increase the boiler output and heat extraction steam flow to complete working conditions 5 and 6, and condition 6 is limited to the pressure rise of the induced draft fan at the boiler side, and the unit reaches the maximum load of 256MW.

2.3. Condensing heat supply unit

| Steam Turbine Units | type          | Rated capacity (Before transformation /MW) | Industrial Extraction Steam (t/h) | Heating and steam extraction (t/h) | Load interval (MW) |
|---------------------|---------------|--------------------------------------------|---------------------------------|-----------------------------------|--------------------|
| #6                  | Double extraction | 220                                       | 0                               | 122                               | 124~206            |
|                     |                |                                            | 0                               | 158                               | 157~197            |
|                     |                |                                            | 59                               | 124                               | 139~194            |
|                     |                |                                            | 62                               | 154                               | 165~183            |
|                     |                |                                            | 61                               | 0                                 | 147~206            |
| #7                  | Double extraction | 330                                       | 0                               | 170                               | 168~285            |
|                     |                |                                            | 0                               | 230                               | 165~275            |
|                     |                |                                            | 50                               | 0                                 | 165~290            |
|                     |                |                                            | 22                               | 170                               | 165~282            |
|                     |                |                                            | 36                               | 225                               | 166~268            |
| #8                  | Double extraction | 330                                       | 0                               | 180                               | 160~278            |
|                     |                |                                            | 0                               | 240                               | 175~277            |
|                     |                |                                            | 20                               | 240                               | 191~265            |
| #9                  | Single extraction | 350                                       | /                               | 140                               | 170~350            |
| #10                 | Single extraction | 350                                       | 260                             | /                                 | 189~310            |

The load ranges of the five condensing units under different working conditions in heating season are shown in Table 3. The maximum electric load of the above five units is limited by the maximum evaporation of the boiler, while the minimum electric load is different.

The minimum electrical load of unit 6 is limited by the following four factors: the steam supply pressure of the first station of the heat supply network should not be lower than 0.08MPa; the minimum opening of the steam inlet control valve of the low-pressure cylinder should not be less than 20%; the
pressure behind the steam inlet regulating valve of the low-pressure cylinder should not be lower than -35.3kpa; and the exhaust temperature of the low-pressure cylinder should not exceed 65℃.

The industrial extraction steam flow of unit 7 is adjusted according to the demand of heat users, and the maximum and minimum electric load are limited by the current external heat supply, the speed of small steam turbine of circulating water pump in heat supply network and boiler negative pressure.

Because the external heating network of unit 8 did not build relay booster pump station according to the design requirements, the pressure required for the external network circulation was provided by the heat supply network circulating pump, and the steam source of the small steam turbine driving the heat supply network circulating pump came from the middle exhaust. In order to maintain the external network circulating pressure, when the inlet valve of the small steam turbine reaches the maximum value, the exhaust pressure of the intermediate pressure cylinder must be kept at a high pressure, and the main steam source needs to be increased. The steam flow is used to maintain the high speed of the small turbine. Therefore, during the minimum electrical load test, when the inlet butterfly valve of the low pressure cylinder reaches the maximum limit value, the unit is higher than the design value at low load.

In the process of load reduction of unit 9, when the inlet steam pressure of low pressure cylinder reaches the minimum value (0.12Mpa) specified in the operation regulations, the unit output will be stopped.

The industrial extraction steam of unit 10 is led out by the rotating diaphragm between the third extraction and the fourth extraction of the intermediate pressure cylinder, and the cold reheater is converged into the extraction steam pipeline as the standby steam source. During the minimum electrical load test, the pneumatic control valve of the cold reheating industrial steam extraction is opened. Because the industrial steam supply pressure of the cold reheater is higher than the extraction pressure of the rotating diaphragm, the industrial steam supply of the cold reheater pushes out the steam extraction of the rotating diaphragm, resulting in the air blowing effect leading to the rotary diaphragm. The temperature of the extraction port of the plate is increased until the limit value of 403℃.

2.4. Test conclusion

2.4.1. Test result. Table 1 lists the unit information, test conditions and test load intervals in detail. Among them, for the high back pressure unit operating under pure exhaust steam condition, the load adjustment range is generally 50%~81% of the rated capacity of the unit; for the extraction condensing unit with heating and extraction steam, when the heating steam extraction amount is the average value of the previous year, the load adjustment range is about 50%~90% of the rated capacity of the unit; for the cogeneration unit after the optical axis transformation, the maximum and minimum external supply of unit 4 optical axis unit is provided. The heat extraction steam flow is 346t/h and 259t/h respectively, and the corresponding unit electrical loads are 113MW and 78MW respectively, and the electric load adjustment range is about 35%~50% of the rated capacity of the unit. For the cogeneration unit after the cylinder cut-off transformation, the maximum heat extraction steam flow of unit 5 is 490t/h and the unit electric load is 264MW. During the operation of cylinder cutting, the maximum and minimum steam extraction flow are 611t/h and 374t/h respectively, and the corresponding unit electrical load is 256MW and 130MW, and the load adjustment range is about 37%~73% of the rated capacity of the unit.

2.4.2. Test limitations. For high back pressure heating unit, 1) The maximum electrical load of the unit is limited by the maximum evaporation capacity of the boiler and the wall temperature of the heating surface of the boiler, the steam water quality, the design output of the denitration, desulfurization, dust removal and slag removal devices of the boiler. The main auxiliary equipment includes the design output of the pulverizing system and six fans, the environmental protection parameters, the maximum steam inlet flow of the steam turbine and the maximum exhaust temperature of the low-pressure cylinder. 2) For the high back pressure heat supply unit with extraction, the minimum electrical load is limited by the minimum steam intake of low pressure cylinder. 3) For high back pressure heating units without
extraction, the minimum electrical load is limited by the minimum stable combustion load of boiler, inlet flue gas temperature of denitration device, wall temperature of heating surface and environmental protection parameters. 4) The monitoring parameters affecting the safety of the unit shall not exceed the alarm value.

For the extraction steam heating unit, 1) Different heat users have different requirements for the extraction parameters, and the extraction parameters of the unit should not exceed the limit value. 2) The minimum electrical load of the unit is limited by the minimum steam intake of the low pressure cylinder, the minimum stable combustion capacity of the boiler, the flue gas temperature at the inlet of the denitration device, the wall temperature of the heating surface, and the environmental protection parameters. 3) For the reheating unit with steam extracted from the exhaust pipe of high-pressure cylinder, when the electric load is low and the amount of heat extraction is large, it is easy to overheat the reheater wall temperature, thus limiting the minimum electrical load of the unit. 4) The exhaust pressure and temperature of intermediate pressure cylinder shall not exceed the limit value of the manufacturer for the unit extracting steam from the connecting pipe of medium and low pressure cylinder. 5) The maximum electrical load of the unit is limited by the maximum evaporation of the boiler, the wall temperature limit of the heating surface of the boiler, the steam water quality, the design output of the denitration, desulfurization, dust removal and slag removal devices of the boiler, and the main auxiliary equipment includes the design output of the pulverizing system and six fans, the environmental protection parameters and the maximum steam inlet flow of the steam turbine. 6) The monitoring parameters affecting the safety of the unit shall not exceed the alarm value.

3. Conclusion
Due to the limitation of "determining power by heat", the capacity of thermal power units to participate in peak load regulation of power grid during heating period is seriously insufficient [6]. In the trend of decreasing utilization hours of thermal power, in the foreseeable future, the range of electric load adjustment of heating units needs to be further expanded, and the dispatch and adjustment of unit load is more and more frequent. Therefore, it is necessary to carry out the load energy of different types of heating units Force research. This paper introduces the relevant information about the actual load carrying capacity test of heating units in Shandong Province, as well as the load adjustment range and load limiting factors of cogeneration unit based on different heating flow, which provides operation reference for power generation enterprises and power grid dispatching.

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