Analysis of heating transformation of different types of thermal power units

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Abstract. This paper introduces the total heating capacity, total installed capacity, heating area change trend and unit transformation of direct regulating heating units in Shandong power grid in recent years. According to the operation data of condensing pumping units, back pressure heating units and cylinder cutting units in previous heating seasons, the heating and peak shaving performance of different types of cogeneration units of the same type, grade and grade in heating seasons are analyzed, It is convenient for the power grid dispatching department to more reasonably and orderly arrange the unit mediation plan of the province's thermal power plants according to the online situation of new energy and external power. At the same time, it is a reference for power generation enterprises to carry out flexible transformation according to the actual situation of units during the 14th Five Year Plan period, and take into account the low load peak shaving performance of units or the whole plant while increasing heating capacity.

Keywords: cogeneration, Peak shaving, reform.

1. Background

Cogeneration unit mainly includes regulating extraction condensing heating unit (hereinafter referred to as extraction condensing unit), back pressure heating unit (including high back pressure circulating water heating unit, optical axis transformation [1] unit, pure back pressure heating unit, etc.), low-pressure cylinder zero output heating[2-3] unit (mainly cylinder cutting unit), etc. As of June 2021, Shandong power grid has directly transferred 154 public thermal power units with a rated capacity of 57305MW, including 137 thermal power units with a rated capacity of 49840MW, accounting for 86.97%. Among the thermoelectric units, the number of condensate pumping units, back pressure units and cylinder cutting units is 88, 33 and 16 respectively, accounting for 79%, 11.79% and 9.21% of the capacity; According to the capacity level, the number of units below 300MW, 300MW, 600MW and 1000MW is 46, 62, 21 and 8 respectively, accounting for 14.23%, 41.37%, 27.99% and 16.41% of the capacity.

After the "carbon peaking and carbon neutralization" double carbon goal was put forward, the power system, as an important link of energy transformation, has accelerated the clean trend of power generation side, and the installed capacity of renewable energy has been increasing; At the same time, Shandong Province issued a notice on flexibility transformation to improve the regulation capacity of power system through flexibility transformation. Under the heating pressure brought by the consumption of renewable energy, urban development and the shutdown of small thermal power, coal-fired power units are facing the dual test of heating and peak shaving[4-6].

2. Heating trend and transformation of thermoelectric units

In the heating season from 2018 to 2019, the total capacity of the public fire electric motor assembly unit directly transferred by Shandong Province is 48215MW, the total heating capacity is 158580701GJ, which is equivalent to 20490 t/h of heating extraction flow and 337084442 ㎡ of heating area; In the heating season from 2019 to 2020, the total installed capacity is 49450MW, the total heating capacity is 167966636GJ, which is equivalent to the heating extraction flow of 21703 t/h and the heating area of 357035499 ㎡; In the heating season from 2020 to 2021, the total installed capacity is 49840MW, the total heating capacity is 190548310 GJ, which is equivalent to 24621 t/h of heating extraction flow and 405035859 ㎡ of heating area.

In 2018-2019, 136 public thermal power units will be directly transferred in the heating season, including 102 condensate extraction units, 31 back pressure units and 3 cylinder cutting units. There will be 139 sets in the heating season from 2019 to 2020 (5 sets of back pressure and cylinder cutting units are reconstructed from condensate extraction units). Compared with the previous heating season, 2 sets of back pressure units will be added: 1 set of 350MW and 1 set of 150MW, 3 sets of cylinder cutting

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units will be added: 1 set of 350MW, 1 set of 330MW and 1 set of 160MW, and 3 sets of condensate extraction units will be added: 1 set of 600MW, 1 set of 335MW and 1 set of 300MW. From 2020 to 2021, there will be 137 sets in the heating season (11 sets of back pressure and cylinder cutting units are transformed from condensate extraction units), one 145MW back pressure unit will be added compared with the previous heating season, and one 135MW back pressure unit will be shut down; 7 sets of 300MW and 3 sets of cylinder cutting transformation units below 300MW are added; Two 680MW condensate extraction units were added, and two 350MW and one 135MW condensate extraction unit were shut down. From the transformation situation, the transformation of back pressure unit is slowing down, and the cylinder cutting transformation has doubled.

3. Performance analysis of different types of thermoelectric units

3.1 Condensate extraction heating unit

Condensate extraction heating unit can supply one or more parameters of steam to the outside world, and its pressure is controlled by the pressure regulating system. This unit can meet the different requirements of external heat load and electric load in a large range, and has flexible operation, so it is widely used.

The heating performance of condensate extraction unit can be determined by three methods: test method[7] , working condition diagram analysis method and thermal calculation method. The test method can accurately reflect the actual heating capacity of the thermal power unit. The unit needs to carry out the load capacity test in the heating season, but there are many test conditions and it is difficult to summarize and sort out due to the limitations of on-site conditions. Thermodynamic calculation method is to calculate the variable working conditions of thermal power units under specific constraints. The calculation process of this method is complex. The working condition diagram method is a method to query the heating capacity of the unit according to the design thermoelectric characteristic curve of the unit. This method is more intuitive and easy to obtain the corresponding results.

The working condition diagram is the relationship curve between the active power of steam turbine generation, main steam flow and regulated steam extraction under different combinations. By digitizing and dimensional conversion of the working condition diagram, the trend diagram of peak regulation upper and lower limits under different steam extraction of the unit can be obtained, and then the calculation model of peak regulation upper and lower limits formula and the calculation model of steam extraction upper limit formula of condensing unit can be obtained.The upper and lower limits of the unit's output under the current steam extraction and the upper limit of the unit's steam extraction under the current output can be obtained by selecting an appropriate section according to the formula[8] . According to the average steam extraction capacity and output of the unit in different heating periods, the electric load adjustment interval under the average steam extraction capacity of different capacity condensing heating units in the initial, middle and final heating periods and the upper limit of steam extraction capacity under 50%, 75% and 100% rated capacity can be obtained by substituting into the calculation model.

According to the analysis of the data of heating season from 2020 to 2021, most condensing units can meet the heating demand by operating at about 60% of the rated load under the average steam extraction capacity of the initial, middle and final stages of heating. Under 50% rated load or minimum heating load, the upper limit of steam extraction capacity of units below 300MW level is about 60 ~ 175 t/h, that of 300MW level units is about 200 ~ 350 t/h, that of 600MW level units is about 500 ~ 600 t/h, and that of 1000MW level units is very small in heating season due to economic operation.

3.2 Back pressure heating unit

The back pressure heat supply unit increases the exhaust pressure of the steam turbine by removing the blades at the end of the low-pressure cylinder of the steam turbine, and uses all the cold source losses for heat supply. Generally, it includes high back pressure circulating water heating unit, optical axis transformation unit and pure back pressure heating unit. The medium and high back pressure circulating water heating units of Shandong direct dispatching public units are generally transformed from units below 300MW level or 300MW level. There are only two optical axis transformation units, the proportion of pure back pressure heating units is very small, and there are many self owned power plants.

The steam extraction heating unit can be transformed into a high back pressure heating unit, and different technical routes can be adopted according to the differences between wet cooling unit and air cooling unit. The operating back pressure of wet cooling unit is generally low, about 5 kPa. Excessive increase of back pressure will affect the operation safety of steam turbine or fail to meet the heating demand. There are two methods for high back pressure transformation of wet cooling unit, that is, removing the last stage blade of low-pressure rotor and one-time transformation of low-pressure rotor. To transform the direct air cooling unit into a high back pressure heating unit, in addition to adding a heating condenser, it is also necessary to partially transform the circulating water pump of the heating network, the heating pipeline and valves in the plant. During the heating period, according to the heating demand, adjust part or all of the exhaust steam to enter the heating condenser to realize high back pressure heating; In the non heating period, close the valves on the heating pipeline, and all the exhaust steam of the steam turbine enters the air cooling island. The indirect air cooling unit is similar to the pure condensing unit. It has a condenser. The exhaust steam condenses in the condenser, and the circulating water exchanges heat through the air cooling tower. The indirect air cooling unit double temperature zone condenser heating technology can be used for heating, which does not change the steam turbine body and intercooling tower.During the heat supply period, the back pressure of the steam turbine shall be properly increased, the circulating water of the heat network shall be used, and the exhaust heat of the steam turbine shall be recovered through the condenser for heat supply; In the non heating period, switch to the pure condensation condition of intercooling tower. Another scheme for high back pressure heat supply transformation of wet cooling unit is to maintain the unit back pressure of 5 kPa in summer, and replace the low-pressure pure condensing rotor with the low-pressure high back pressure rotor in winter, so as to increase the heating back pressure, such as about 50 kPa. After the heating period, replace the low-pressure pure condensing rotor again. Because two different low-pressure cylinder rotors are used in heating period and non heating period, it is called double rotor double back pressure exchange heating technology. This technology is applicable to the reconstruction of circulating water waste heat recovery of large units. In terms of safety, it solves many problems of high back pressure heating, but at the same time, this technology also has corresponding defects, that is, it digests the huge residual heat entering the exhaust steam of condenser, which requires a large and stable heating area.

The electric load of high back pressure heating unit is determined by the heat load it undertakes. The greater the heat load, the greater the steam exhaust required by the unit, and the higher the corresponding main steam and electrical load. Since Shandong high back pressure heating units operate stably throughout the heating season, the load trend is almost a straight line. Select different levels of high back pressure units, and directly transfer the unit load, circulating water flow, inlet and outlet temperature and other relevant data in a certain period to obtain the heating capacity and converted steam extraction capacity of these units, easy to compare.

The operation load of the high back pressure unit in the heating season is generally 50% ~ 75% of the rated load. Because the high back pressure heating unit makes use of all the cold source losses of the unit, the heating capacity is higher than that of the condensate extraction unit of the same grade. Generally, when the high back pressure heating unit below 300MW is converted into steam extraction capacity, it is about 200 ~ 300t/h, which is equivalent to the heating capacity of 300MW condensate extraction unit. When converted into steam extraction capacity, 300MW high back pressure heating unit is about 350 ~ 600t/h, which is equivalent to the heating capacity of 600MW condensate extraction unit. Based on the high back pressure unit's efficient heating capacity and good economic benefits, it should give priority to bear the maximum heat load.

Like the high back pressure unit, the optical axis unit operates stably throughout the heating season with almost no adjustment. Among the two optical axis units, one unit has a rated capacity of 110MW, an operating load of 62MW in the heating season, and an average steam extraction capacity of 280t/h; The other unit has a rated capacity of 225MW, an operating load of 113MW in the heating season, and an average steam extraction capacity of 345t/h. After the optical axis transformation, the daily operation load of the unit in the heating season is at a low level, but it has strong heating capacity.

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3.3 Low pressure cylinder zero output heating unit

The low-pressure cylinder zero output heating unit is mainly transformed by cylinder cutting. After the strength check of the last two stages of blades, the original steam inlet pipe of the low-pressure cylinder is cut off, a bypass pipe is added in the medium and low-pressure connecting pipe, and a small amount of steam after check and calculation is used to take away the blast heat generated by the rotation of the low-pressure rotor after "cylinder cutting". The "zero output" operation of the low-pressure cylinder is realized by cutting off the low-pressure cylinder, which greatly reduces the electrical load of the unit and meets the deep peak shaving demand of the power grid, so as to realize "thermoelectric decoupling". The operation data of some cylinder cutting units in cylinder cutting and non cylinder cutting states are shown in Table 5.

With the decrease of volumetric flow, the efficiency of the stage will become worse. When the volume flow rate decreases to a certain value, the wheel circumference power of the stage is equal to zero; If the volume flow is further reduced, the stage will change from the original work stage to the blast power consumption stage, and the stage efficiency will change from positive to negative. At this time, the stagnation enthalpy of exhaust steam will be higher than the inlet stagnation enthalpy, blast friction will heat the steam flow, and the temperature of blades will also rise, causing cylinder deformation and excessive blade stress. When the low-pressure cylinder enters the blowing condition, the exhaust water spray device is usually set to reduce the exhaust temperature of the last stage. Under small volume flow, the last blade root works with negative reaction, and the water spray from LP cylinder will be sucked back into the moving blade through the last blade root, and with the vortex movement, the water droplet will be sucked back to erode the last blade root; The small flow rate greatly increases the outlet angle of the stationary blade, resulting in water droplets scouring to the back of the steam inlet side of the moving blade, resulting in erosion. The above two flow modes of water droplets do great damage to the blade and weaken the strength of the blade. At the same time, under the condition of small volume flow, the large negative angle of attack at the inlet of the last stage moving blade causes large-scale steam flow separation and induces self-excited vibration, resulting in the sudden increase of dynamic stress level and stall flutter. In relative volume , In the process of flow reduction, when the relative volume flow is low to a certain value, the blade vibration stress begins to increase rapidly, then reaches the maximum value, further reduces the volume flow, the vibration stress decreases gradually, and the vibration stress changes non monotonically with the relative volume flow. Therefore, there is a large dynamic stress amplification interval for the last stage blade at the relative volume flow of 0.1 ~ 0.2. During operation, try to avoid long-term operation in this working condition interval.

Table 1 Operation data of cylinder cutting unit in cylinder cutting and non cylinder cutting state

Unit level	Unit capacity (MW)	No cylinder cutting state		Cylinder cutting state			
		Maximum extraction capacity (t/h)	Output range(MW)	Close to the maximum steam extraction without cylinder cutting (t/h)	Corresponding load(MW)	Maximum extraction capacity (t/h)	Corresponding load(MW)
Below 300 MW	160	241	110 ~ 126	233	82	314	104
300 MW class	300	433	171 ~ 221	434	118	651	178
	330	452	231 ~ 267	452	132	667	218
	330	305	151 ~ 286	305	90	642	192
	350	510	283 ~ 294	510	203	640	283

In the 300MW class, the cylinder cutting transformation unit occupies the mainstream position. The maximum steam extraction capacity of the unit after transformation is about 650t/h, which is about 140 ~ 340t/h higher than that before transformation. Under the same load, the heat supply capacity of the unit after cylinder cutting is greater than that of the high back pressure unit. The operation time of the reformed heating unit is divided into two states: no cylinder cutting and cylinder cutting. Under the condition of constant external heating load, cylinder cutting can reduce the power generation by about 30% compared with no cylinder cutting.

Among the grades below 300MW, the heating type is the most comprehensive. Take 160MW unit as an example, the two units are high back pressure and cylinder cutting heat supply units. Before the transformation, they are the same type units produced by the same manufacturer, and the model is N150/CC135-13.24/535/535/0.981/0.23. The maximum steam extraction capacity after cylinder cutting transformation is similar to that of high back pressure unit and 110MW optical axis unit under daily operation, and can expand the steam extraction capacity by about 70 t/h compared with that of condensate extraction unit at the same level; At the same time, under the same heating level, the optical axis unit has the lowest operating load, but has no peak shaving capacity under the condition of constant heating capacity.

4. Conclusion

During the "14th five year plan" period, Shandong direct coal-fired power generation unit is required to carry out flexible transformation according to 20% of the capacity every year. The heating season of the existing condensate extraction unit is limited by 50% of the thermal power ratio, and the minimum output should reach 30% and 40% of the rated capacity. With the increase of heat load and the fluctuation of coal price in recent years, the contradiction between unit heating and peak shaving in heating season in Shandong Province is gradually deepened, and there are more flexible modifications of unit heating. The power generation enterprise shall flexibly transform according to the actual situation of the unit, and take into account the low load peak shaving performance of the unit or the whole plant while increasing the heating capacity.

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References

[1] Ronghe Hao, Zhuang Li, Liping Wang , et al. Economic Analysis of Smooth Shaft Operation of Low Pressure Cylinder in 210 MW Unit[J]. Journal of Shenyang Institute of Engineering (Natural Science), 2020,16(02):25-28+44.

[2] Jianxun Wang. Analysis of Flexible Peak-Load Ｒegulation Capability and Economy on the Zero Output Technology of Low-Pressure Cylinder for 650 MW Supercritical Unit[J].Journal of Engineering for Thermal Energy and Power, 2021,36(02):18-23.

[3] Tianfu Liang, Weiyang Xie, Fei Wang, et al.The key technique research of removing the low pressure cylinder of steam turbine[J].Turbine Technology, 2019, 61(6): 471–472.

[4] Haisheng Yang, Tuo Zhang , GuangTong Tang, et al. Influence of Zero-Output Technology of Low-Pressure Cylinder on Deep Peak Regulation Performance of Heating Unit and Compensation Standard for Peak Regulation[J]. Journal of Engineering for Thermal Energy and Power,2020,35(06):268-273.T

[5] Qinpeng Zhang, Xuedong Wang, Feng Li, et al. Analysis of Heating Capacity and Peak-regulating Capacity of 330 MW Steam Turbine Unit With Low-pressure Cylinder off Operation[J]. Shandong Electric Power, 2020, 47(12):72-76.
[6] Puxin Shi, Peiran Shi, Peiwen Wang, et al. Analysis and Operation Evaluation of Power Peak-shaving Ancillary Service Market in North China[J]. Automation of Electric Power Systems, 2021,45(20):175-184.
[7] Xuhui Zhang, Zhonghua Zhao, Fuxing Cui, et al. Experimental Research on Deep Peak Regulation Characteristics of 1030 MW Ultra Supercritical Unit[J]. Shandong Electric Power, 2021, 48(02):58-62.
[8] Lingkai Zhu, Wei Zheng, Junshan Guo , et al.Application of Heat Load Distribution in Improving Peak-shaving Ability of Plant[J]. Power System Engineering, 2019,35(06):43-46+49.