Prospect of Peak Regulation Capacity Improvement through Flexibility Transformation of Combined Heat and Power Units in Shandong Province

Zhiqiang Gong *, Yue Han, Junshan Guo, Panfeng Shang, Lingkai Zhu

State Grid Shandong Electric Power Research Institute, Jinan, 250003, China

Abstract: With the high proportion of renewable energy connected to the grid, peak shaving demand surge, which needs to enhance the flexibility of coal power with a larger proportion to support the stable operation of the grid. At present, the capacity of the combined heat and power unit accounts for about 87 % of direct dispatching coal-fired power plants by Shandong power grid. The flexible operation ability of the combined heat and power unit is poor, and its flexible transformation is urgent. This paper summarizes the current relatively mature flexibility transformation technology of combined heat and power unit, including low pressure cylinder zero output transformation (cylinder cutting transformation), bypass load regulation, thermal energy storage and electrical energy storage transformation technology, and puts forward to encourage the flexibility transformation of in-service combined heat and power unit, and actively promote the research and application of the intelligent heating network, the integration of thermal and electricity, and the clean heating construction and clean heating technology.

Key words: Carbon peaking and carbon neutrality, combined heat and power unit, flexibility transformation, peaking regulation.

1. Introduction

Since the goal of "carbon peak by 2030 and carbon neutral by 2060" was put forward, China has proposed to build a clean, low-carbon, safe and efficient energy system, control the total amount of fossil energy, focus on improving utilization efficiency, implement renewable energy substitution action, deepen power system reform, and build a new power system with new energy as the main body. These policies and measures will lead to substantial adjustment of power supply structure, and the thermal power generation industry will face huge challenges. Under this background, the proportion of new energy power generation in China's power structure will continue to increase. With the significant increase of installed capacity of intermittent and random renewable energy, as well as the impact of trans regional power transmission, coal power units with large capacity will transform to flexible power supply adjustment and actively participate in deep peak shaving, which puts forward higher requirements for peak shaving capacity of thermal power units. On the other hand, central heating has the advantages of high energy comprehensive utilization efficiency, energy conservation and environmental protection. The proportion of heating units in northern China is high, but the proportion of large condensing heating units is too large to fully participate in deep peak shaving. Therefore, it is urgent to carry out efficient research on flexible peak shaving of heat supply units to improve the peak shaving capacity of heat supply units.

2. China's energy structure and carbon emission status

2.1 China's energy structure

Data statistics show that in the post epidemic situation, China's primary energy demand will increase by 2.1% in 2020, lower than the average annual growth rate of 3.8% in the past decade, but it is also one of the few countries with increased energy demand[1]. China continues to promote the optimization of energy structure, and the proportion of coal in China's primary energy consumption structure will be reduced to 57% in 2020. The growth of renewable energy in China accounts for one third of the growth of global renewable energy consumption. Among them, wind energy (+14%) and solar energy (+15.8%) increased significantly. In 2020, China's installed wind power capacity increased by 72 million kilowatts, which exceeded the total increase in the past three years.

* Corresponding author: zhqgong@foxmail.com

2.2 Current situation of carbon emissions in China

In 2020, China's coal demand will increase by 0.3%, driven by the demand growth of power, building materials, steel and chemical industries. Coal imports were the highest since 2014. In 2020, China's carbon emissions will increase by 0.6%, making it one of the few regions in the world to increase. China's carbon emissions have continued to grow for the fourth consecutive year, ranking first in the world, reaching about 10 billion tons (Figure 2). China's carbon emissions have increased to about 31% of the total global carbon emissions[2].

China's carbon consumption and CO2 emissions mainly come from coal-fired power plants. According to the data of the National Bureau of Statistics, China's total power generation in 2020 will reach 7417.04 billion kWh, of which the total thermal power generation will reach 5279.87 billion kWh, with a cumulative growth of 1.2%, accounting for 71.2%. In recent five years, the proportion of thermal power generation in China's total power generation has declined year by year. However, as the base of thermal power is still large, the total amount of CO2 generated during coal combustion remains at a high level. In 2020, the total amount of CO2 generated from coal utilization will be close to 8 billion tons.

2.3 Necessity of flexibility transformation of thermal power generator set

The proposal of the 3060 policy has brought great opportunities and challenges for China to continue to promote the transformation of the energy structure and build a new power system. Thermal power generation units are the main source of carbon emissions in China. The proposal of 3060 policy and the pressure of new energy consumption make thermal power generation units face great pressure of transformation. The installed capacity and power generation of new energy will continue to grow. It is estimated that in 2035, the installed capacity of non-fossil energy power generation will account for 68.4%, and the installed capacity of new energy power generation will account for 54.7%. Non-fossil power generation accounted for 56.4%, and new energy power generation accounted for 32.9%. Electric energy accounts for 39.69% of terminal energy consumption[1].

Although the energy structure situation dominated by coal will not change in the near future, under the background of "dual carbon", with the substantial increase in the installed capacity and power generation proportion of clean energy power, the peak shaving demand of the power grid also increases significantly. As the main peak shaving capacity in the recent stage, the direct dispatching coal-fired power plants will undertake an important peak shaving task, and the coal power units need to actively transform from the electricity based power supply to the electricity based and power regulated power supply. Therefore, coal power generation units need to be flexibly transformed to improve the new energy consumption capacity to meet the safe and stable operation of the power grid.

2.4 Current situation of heat supply units in Shandong Province

By December 2021, there were 161 direct dispatching coal-fired power plants with a total capacity of 60.92 million kilowatts in Shandong Province. Among them, there are 147 thermal power units with a capacity of 52.9 million kilowatts, accounting for 86.8%. Among thermal power units, there are 86 condensing units, 34 back pressure units and 27 low pressure (LP) cylinder cutting units. The back pressure unit basically loses the flexibility adjustment ability. The unit operated with LP cylinder cutting realizes the weak decoupling of thermoelectricity. The designed minimum technical output can be reduced to less than 50% of the rated capacity. The flexible operation ability of the condensate extraction unit is poor. The demand for flexibility transformation of heating units in Shandong Province is urgent.

By the end of the 14th Five Year Plan period, all the direct dispatching coal-fired power plants in Shandong Province need to complete the flexibility transformation. After transformation, the minimum technical output of the unit under the pure condensation condition reaches 30% of the rated capacity, and the adjustable range of the unit is expanded to 30~100% of the rated capacity. The heating unit shall meet the minimum technical output of 40% of the rated capacity under the heating capacity. Therefore, the flexibility transformation of heat supply units is an important work to improve the capacity of regulated power supply in Shandong Province[3].

3. Flexibility transformation technology of heat supply unit

3.1 LP cylinder zero output transformation (cylinder cutting transformation)

For the condensate extraction unit using bridge tube for heat supply, the maximum steam extraction volume is limited by the minimum steam inlet volume of the LP cylinder. For safety reasons, the manufacturer reserves a large margin for the minimum steam inlet volume of the LP cylinder, which cannot give full play to the heat supply capacity of the unit. However, through verification and calculation, the steam inlet volume of the LP cylinder with 3% of the rated main steam flow is generally enough to take away the blast heat. The technical transformation of zero output (cylinder cutting) operation of LP cylinder is applicable to units with large demand for heat supply. In the heat supply state of the unit, the LP cylinder is in a high vacuum environment by removing most of the steam inlet from the LP cylinder of the turbine, increasing the heat supply capacity of steam extraction, and improving the peak shaving depth and heat supply capacity of the unit.

The cylinder cutting technology does not need to modify or replace the rotor, only the strength check of last stage and secondary last stage blades is required. The cost of transformation is low. During cylinder cutting operation, it can freely switch between back pressure working condition and condensate extraction working condition. After the LP cylinder is cut, intermediate pressure (IP)

cylinder exhaust are completely used for heating, with strong heating capacity. However, the blade may be damaged due to water erosion and air blowing loss during long-term operation of LP cylinder cutting[4].

3.2 Bypass load regulation technology

The bypass load regulation technology is generally divided into two technical schemes: steam turbine high pressure (HP)/LP bypass combined steam extraction heating and LP bypass steam extraction heating[5]. Combined bypass steam extraction refers to the use of HP bypass to reduce the temperature and pressure of some main steam and then send it to HP cylinder for steam exhaust. After being heated by the boiler reheater, the steam is extracted from LP bypass (IP cylinder inlet) for external heating. LP bypass steam extraction is to directly introduce some reheated steam for external heating by using LP bypass pipeline. The bypass load regulation technology has a small investment and can increase the peak regulation capacity by 10-20% of the rated capacity.

3.3 Thermal energy storage transformation technology

3.3.1 Hot water tank energy storage technology

The hot water tank energy storage technology of thermal power plants has been widely used at home and abroad, mainly for thermoelectric decoupling of heating power plants, to improve the flexibility of heating unit operation. The steam turbine is used to extract steam, heat the return water of the heat network to the heating temperature, and store it in a large hot water tank, so that the unit can store hot water energy during the period of high power load and low heating load. When the power load is low and the heating load is high, the energy storage system can provide heat. On the basis of meeting the heating requirements, the flexibility of unit operation can be improved, so that the cogeneration unit can participate in peak shaving[6].

According to the different heat storage capacity, the hot water tank energy storage technology can increase the peak shaving space of the original thermoelectric unit by 30~50% of the rated capacity, so that the thermoelectric unit can be reduced from 60~70% of the load under the previous heating state to 30~40% of the rated capacity, which is basically equivalent to the unit state under pure condensation.

3.3.2 Electrode boiler heating technology

The electrode boiler is a kind of electric boiler that is widely used in the industrial and civil heating markets at present. Unlike ordinary electric heating equipment, the electrode boiler uses high-voltage three-phase electrodes to directly discharge heat in the conductive brine in the boiler, so that the electric energy can be converted into heat energy with high conversion efficiency, and then the heat in the furnace can be transferred to the heating network through the heat exchanger. It has the advantages of large power, fast and smooth adjustment, etc. As an electric energy consumption equipment, the electrode boiler can directly reduce the output of the thermal power plant and increase the heating capacity, which is an effective peak shaving technology[7].

At present, electrode boilers are widely used in industrial heating and civil heating. This technology has the advantages of high power, fast and smooth adjustment, etc. The electrode boiler consumes the output power of the generator. According to different configurations, the capacity of the original thermal power unit can be increased by more than 50~70% of the rated capacity peak shaving capacity, or even zero output operation. However, the electric boiler does not have the heat storage performance. Under the restriction of heat load, the adjustment power of the electric boiler needs to be coordinated with the boiler adjustment load, so the deep peak shaving is limited. In addition, in the process, electric energy and heat energy are transformed mutually, and the economy of energy utilization is poor.

3.3.3 Regenerative electric boiler

The regenerative electric boiler refers to the use of electric boilers to convert electric energy into heat energy of high-temperature solids, and use the sensible heat of high-temperature solids to store heat energy[8]. When heat energy is needed, the heat energy of the heat storage body is converted into hot water, steam and other forms of heat use. The boiler uses the electric heating wire inserted in the heat exchange air duct at the bottom to heat the electric heating wire. During the heating cycle, the heat accumulator absorbs the heat released by the electric heating wire and temporarily stores it. The heat release cycle is released through the secondary heat exchange for users to use.

The investment cost of electric boiler solid heat storage technology is high, and the process involves electro thermal conversion. High grade electric energy is converted into heat energy, which is less economical in energy utilization and high in operation cost.

3.4 Battery energy storage transformation scheme

Battery energy storage can effectively improve the peak shaving capacity of the unit. When the thermal power unit needs to reduce the load, only part of the generated energy needs to be charged to the electric energy storage facility to reduce the grid connected load. When the thermal power unit needs to carry full load, the electric energy storage facility can discharge the grid, which can improve the overall output of the thermal power unit. However, the peak shaving capacity of the thermal power unit itself (high and low load range) is far less than that of the pure condensing unit, and the cost of electric energy storage is significantly higher than that of thermal energy storage. Therefore, to achieve the perfect peak shaving state (100~50% or even lower), large capacity and high-power electric energy storage equipment need to be configured, with huge investment costs[9].

4. Prospects for flexibility transformation of heat supply units to improve peak shaving capacity

4.1 Flexibility transformation of in-service heating units

Shandong Province will continue to promote the implementation of flexible manufacturing and flexible transformation of coal fired power generation units, encourage the in-service heat supply units to give priority to the use of mature technologies to implement flexible transformation, improve the flexibility regulation level of heat supply units and release the peak shaving capacity on the basis of ensuring or further improving the heat supply capacity and meeting the needs of new heat load[10]. This will help promote the transition from basic power supply to regulatory power supply of coal power units.

4.2 Research and application promotion of intelligent heating network and thermoelectricity integration

During the centralized heating period in Shandong Province, the capacity of peak load regulation and frequency regulation of heating units is greatly limited. In order to increase the peak shaving margin of heating units, the current heating mode with constant heat flow of heating units should be changed. The peak shaving capacity of heat supply units shall be improved by taking advantage of the different heating demands in different periods of the heat network and the thermal inertia of the heat network. It is estimated that the heat users will not feel obvious abnormality if the heating network in large cities stops heating for one hour. However, for thermal power units, huge peak shaving space can be released within one hour to meet the short-term peak shaving demand of the power grid.

4.3 Clean heating construction and clean heating technology R&D and application promotion

It is necessary to fully respect the will of the masses and accelerate the increase of the proportion of clean heating. At present, the market mechanism of clean heating is not mature, and technology research and development and promotion are not enough. It is suggested that the government make top-level design and issue relevant policies, guide each city to actively select applicable clean heating technologies, mobilize the enthusiasm of enterprises and heat users to participate in clean heating projects.

5. Conclusion

Under the background of "double carbon", the proportion of new energy power generation will be greatly increased, and coal power generation units are required to actively participate in deep peak shaving. At present, the capacity of heating units accounts for about 87% of the direct dispatching public coal-fired power units in Shandong Power Grid, with poor flexibility and urgent transformation needs.

The flexibility transformation technology of heat supply unit mainly includes zero output transformation of LP cylinder (cylinder cutting transformation), bypass load regulation technology, thermal energy storage transformation technology and electric energy storage transformation technology. It is necessary to encourage the flexible transformation of in-service heating units, and actively promote the development, application and promotion of intelligent heating network, thermoelectricity integration, and clean heating technology.

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