Development prospect of heat supply and peak shaving of nuclear power units in Shandong power grid

Lingkai Zhu [1], Wei Zheng[1], Ziwei Zhong [1], Zhiqiang Gong [1], Junshan Guo [1]

State Grid Shandong Electric Power Research Institute, Jinan, China

Abstract. Under the current national "dual carbon" economic development goal, nuclear energy, as a clean, low-carbon, safe and efficient form of energy, has the advantage of natural heat. Central heating is an important area that consumes coal and generates carbon emissions. Therefore, the development of nuclear heating is conducive to improving the energy utilization structure and upgrading the industry. Based on the current situation of the nuclear motor assembly machine in Shandong Province and the power supply composition structure of the provincial power grid, this paper has carried out the relevant technical analysis and prospects for the peak shaving of nuclear heating.

1. Introduction

In October 2021, the State Council issued the Action Plan for Carbon Peak by 2030, which proposed to "actively, safely and orderly develop nuclear power" and "actively and steadily carry out demonstration of nuclear heating"[1]. This is the second time since the government work report in March 2021 first proposed "actively and orderly develop nuclear power on the premise of ensuring safety", and the central government mentioned "actively, safely and orderly develop nuclear power", which means that nuclear power may usher in a new round of development opportunities.

By the end of 2016, the heating area of urban and rural buildings in northern China was about 20.6 billion square meters, the heating coal used was about 400 million tons of standard coal[2]. Nuclear heating is a safe, simple, mature and reliable technology. If it can be successfully used for urban heating and popularized, it will help alleviate the haze problem caused by coal heating[3]. As of June 2022, China has 54 nuclear power generating units in operation, 23 nuclear power generating units under construction, and the number of nuclear power generating units under operation and construction is the second in the world. It is estimated that by 2025, the installed capacity of nuclear power operation in China will reach about 70 million kilowatts[4].

Shandong Province is a traditional large heating province. After the "double carbon" goal was proposed, the task of reducing coal combustion in Shandong Province was severe. A large number of small thermoelectric and small boilers were shut down, and large direct dispatching public thermoelectric units were used to replace heat supply. The heating area of directly transferred public thermal power has increased year by year with a compound growth rate of 10%. It will be 341.84 million square meters in 2019, 379.33 million square meters in 2020, and 413.29 million square meters in 2021. At the same time, the proportion of heat supply transformation has increased year by year. By the end of 2021, the number of directly transferred public thermal power medium heat motor units has reached 144 [5], the installed capacity is 51.985 million kilowatts, and the installed proportion is close to 90%. There are only 13 pure condensing units in the province, The number and capacity of direct transfer public thermal power heating transformation have reached the limit, so vigorously developing nuclear power heating can effectively supplement the heating gap caused by the shutdown of small units, while meeting the development requirements of clean and low-carbon.

Shandong Province is a typical receiving power grid. In 2021, the maximum load of incoming electricity from outside the province will reach 21.47 million kilowatts, accounting for one fourth of the maximum load of power consumption in the whole society. The total installed capacity of wind power and photovoltaic has exceeded 40 million kilowatts. The power supply composition of Shandong power grid is becoming increasingly complex. External power does not participate in peak shaving, and the uncertainty of wind and solar grid connection is characterized by "reverse peak shaving". In the case of low pumped storage capacity in the province, the peak shaving of the power grid mainly depends on thermal power, This has also brought about two major problems. First, the coal price has remained high in the past two years, the thermal power is in a state of substantial loss, and the willingness to take the initiative to generate electricity has fallen to the freezing point. The situation of power supply guarantee is severe; Second, the direct transfer of public thermal power heating has increased year by year, and the peak shaving capacity affected by heating has decreased significantly in the heating season.

* Corresponding author: zhulingkai@woyoxin.com

The contradiction between heating and peak shaving is prominent.

2. Status quo of nuclear heating peak shaving in Shandong Province

At present, the nuclear power installed capacity in Shandong Province is two 1250MW imported AP1000 third-generation nuclear power units in Haiyang Nuclear Power Station Phase I of Shandong Nuclear Power Co., Ltd. According to the Action Plan for Shandong Nuclear Energy Development and Construction Project issued by Shandong Provincial Energy Administration, by 2025, the installed capacity of nuclear power in operation and under construction in the province will be more than 13 million kilowatts, including 5.7 million kilowatts in operation and 30 million square meters of nuclear heating area; In 2030, the installed capacity of nuclear power in operation and under construction in the province will be more than 30 million kilowatts, including 13 million kilowatts in operation and installation, and the nuclear heating area will be 200 million square meters. During the 14th Five Year Plan period, nuclear power in Shandong Province will usher in a period of rapid development, and the impact of nuclear power on people's livelihood heating and grid peak shaving will gradually increase[6].

In terms of nuclear power heating, the low parameter steam extraction of nuclear power unit steam turbine is used for urban heating in nearby areas, realizing the energy ladder utilization of nuclear power, improving the thermal efficiency of nuclear power units, further reducing the carbon emissions and soot emissions in this area, and improving the contribution of nuclear power to regional environmental protection. Since 2019, Haiyang Nuclear Power has begun to undertake part of the people's livelihood heating tasks in Haiyang urban area. In Phase I, part of the plant auxiliary steam is extracted for external heating, with the maximum extraction capacity of 50t/h. On November 15, 2021, Shandong Haiyang Nuclear Power Heating Phase II Project will be put into operation. High exhaust steam extraction of Unit 1 will be adopted for external heating, with the maximum steam extraction volume of 346t/h. The heating area of Haiyang Nuclear Power will reach 5.2 million square meters, covering the urban area of Haiyang. Haiyang Nuclear Power Unit 1 will replace 12 coal-fired boilers, becoming the largest cogeneration unit in the world. On April 1, 2022, the "Nuanhe No.1" Haiyang Nuclear Energy Heating Project exceeded the heating task in the first heating season, providing 2 million GJ of clean heat and nearly 5 million square meters of heating area. Compared with coal-fired heating, nuclear heating saved 180,000 tons of raw coal consumption, reduced the amount of heat released to the environment decreased by 1.5 million GJ[7].

In terms of nuclear power peak shaving, the current load adjustment of nuclear power units is realized by regulating the output power of nuclear reactors. In the operation of PWR nuclear power plant, the control rod displacement and boron solution concentration are generally used as control variables to achieve the reactor load tracking control, which has a great impact on the life and operation safety of nuclear power units. Therefore, based on safety, economy and other considerations, Haiyang Nuclear Power does not participate in the peak shaving of the power grid at present, but operates with basic load. However, with the increasing peak valley difference of Shandong power grid and the pressure of new energy consumption, the demand for peak shaving of the power grid is increasing, and nuclear power peak shaving is gradually put on the agenda.

3. Development of Nuclear Power Heating and Peak shaving Technology at Home and Abroad

3.1 Research status and development trend abroad

In terms of nuclear heating, Bento et al. conducted safety evaluation on SECURE low-temperature nuclear heating stations developed in Sweden and Finland in 1978[2]. Rämä and others put forward a concept of flexible nuclear cogeneration system. Nuclear power plants operating according to this concept can use steam at different pressure levels to adjust the heat and electricity produced. In terms of nuclear power cogeneration heating, in 1964, the first nuclear power heating project in the world was put into use in the coastal area of the Swedish city of Ågesta. The main function of the nuclear power plant is to provide central heating and produce a small amount of electricity for Farsta, a suburb of Stockholm. In 1969, Miller of the Oak Ridge National Laboratory of the US Department of Energy proposed a nuclear power cogeneration system[8]. This system can provide most of the heat energy for the heating system or air conditioning system of nearby cities by using the heat from the back pressure steam turbine unit of the nuclear power plant or the secondary circuit of the nuclear power plant, and reduce the waste of the heat energy of the nuclear power plant.

In terms of nuclear power peak shaving, Westinghouse PWR nuclear power unit has achieved the record of more than 600 daily load tracking operations in four consecutive refueling cycles. The pressurized water reactor units in France are capable of peak regulation from the design point of view. During the first 65% life cycle of the fuel, the minimum output can be reduced to 27% of the rated power. During the first 65% - 90% life cycle of the fuel, the adjustable range of the units decreases linearly. The minimum technical output gradually increases. At 90% - 100% life cycle, the units do not have the capacity to regulate. Because nuclear power units account for a large proportion, France frequently participates in peak regulation of the power grid.

3.2 Research status and development trend in China

At present, China has the third generation nuclear power technology of "Hualong No.1" and "Guohe No.1". In terms of nuclear heating, China has developed "Yanlong", NHR-200I, NHR-200II and other types of low-temperature heating reactors. Xu Jiming briefly described the status and role of nuclear energy in the current energy development of the world and China, including the principles and technical route recommendations that should be followed for the development of nuclear heating[9]. Zhou Zhengdao et al. took the AP1000 third generation million nuclear power unit as an example to compare and analyze the two heat supply schemes, such as HP cylinder steam extraction and reheat hot section steam extraction, and introduced the impact of each steam extraction scheme on the unit's economy and safety[10]. Taking the AP1000 nuclear power generation unit as an example, Wu Xinzhuang and others proposed to use the absorption heat pump to extract the heat of the nuclear island equipment cooling water and the conventional island closed cooling water system as the first stage heating of the heat network, recover the waste heat of equipment operation, improve the unit economy, and then provide hot water after further heating through the heat network heater[11]. Low temperature heating nuclear reactors have not been popularized and applied in China due to factors such as economy and residents' sensitivity, and cogeneration of nuclear power units has been commercially applied in Haiyang Nuclear Power Plant.

In terms of nuclear power peak shaving, the control rod displacement and boron solution concentration are generally used as control quantities to achieve the reactor load tracking control, which can achieve "12-3-6-3" daily load tracking, that is, 12 h full output at peak load, 3 h linear load reduction at night, 6 h operation on low power platform (generally 50% rated power), and 3 h linear load increase at morning to full output. However, the above regulation modes have adverse effects on the operation safety and economy of the unit. Therefore, domestic scholars have proposed joint peak shaving and auxiliary peak shaving by comprehensive utilization of nuclear energy, and Zhao Jie has proposed the mode of pumped storage combined with nuclear power peak shaving, which can meet the peak shaving demand of the power grid and ensure that nuclear power has basic load[12]. Gao Xiaotian investigated the status quo of hydrogen energy preparation, storage, transportation and utilization, explored the hydrogen energy storage technology route suitable for nuclear power peak shaving, and analyzed the economic benefits of different hydrogen energy utilization technology routes by taking the existing operation of a nuclear power plant as an example[13]. Yang Zhenshuai proposed a peak shaving system and operation method of nuclear power plant based on compressed air energy storage, which can realize full gradient peak shaving of nuclear power plant under the premise of ensuring the safe operation of nuclear power generator set at rated load[14]. Lin Yi proposed a nuclear power peak shaving system and method based on seawater desalination technology, which can meet the requirements of nuclear power generator units to participate in peak shaving by means of hydropower generation, and extend the operation time of nuclear power with base load[15].

4. Summary and outlook

At present, there are two main methods for nuclear power peak shaving. One is to participate in peak shaving by adjusting the power of nuclear reactor, and the other is to cooperate with hydrogen production, energy storage, seawater desalination and other comprehensive utilization methods to participate in peak shaving. For nuclear power units that are responsible for heat supply, extracting some steam from the turbine side for heat supply will reduce the output of the unit. If "thermoelectric decoupling" can be achieved, the output reduction caused by heat supply will become a peak shaving resource instead, The unit output can be changed by adjusting the steam extraction volume without regulating the output power of the nuclear reactor to participate in the peak shaving of the power grid. Taking Haiyang Nuclear Power as an example, at present, the high pressure exhaust steam extraction capacity of Haiyang Nuclear Power for external heating is 300t/h, which affects the output of the unit by about 50000 kilowatts. If Haiyang Nuclear Power realizes "thermoelectric decoupling" by adding heat storage tanks, electric boilers, etc., the unit can flexibly operate within the load range of 1.2-125 million kilowatts to participate in peak shaving of the power grid. Therefore, the exploration of a new mode of nuclear power generator units participating in power grid peak shaving through "thermoelectric decoupling" has avoided the potential safety hazard of traditional peak shaving by adjusting nuclear reactor power, which is conducive to promoting the participation of provincial nuclear power generator units in peak shaving, and it is urgent to carry out research. Relying on the mature thermal power heating transformation technology route, it is of great significance to carry out the research on the heating transformation and economic evaluation of nuclear power units, to promote the substitution of nuclear power for thermal power heating, and to help achieve the goal of "double carbon".

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