E3S Web of Conferences **416**, 01010 (2023) https://doi.org/10.1051/e3sconf/202341601010
OGEGS 2023

Analysis of Heating Transformation of Nuclear Power Units

Lingkai Zhu*, Ziwei Zhong, Qian Wang, Kai Liang, Zhiqiang Gong, Junshan Guo, Wei Zheng, Panfeng Shang

State Grid Shandong Electric Power Research Institute, Jinan, China

Abstract. Under the current national conditions and policy support, nuclear heating has flourished. Domestic nuclear power units mainly generate electricity, and nuclear heating as a clean energy source is one of the main ways to solve winter heating in the north. This paper first compares and analyzes the two different ways of nuclear heating, then takes the nuclear heating of Haiyang Nuclear Power Station as an example, based on the mature experience of steam extraction heating transformation of thermal power units, makes an economic analysis on the steam extraction transformation of PWR nuclear power units from the characteristics of the thermal system combined with the Spot market, and finally makes an economic evaluation on the Cogeneration nuclear power units.

1. Introduction

With the acceleration of urbanization and the continuous increase of urban central heating area in China, the heating area in 2020 was 9.882 billion square meters, and it is expected to reach 15 billion square meters by 2030[1]. Driven by the "dual carbon" goal, the proportion of thermal power units in the power supply structure is gradually decreasing, providing opportunities for the development of nuclear heating.

Since 2016, the country has issued several policies to promote the development of nuclear heating. Among them, the National Development and Reform Commission and the Energy Administration jointly released the "Action Plan for Energy Technology Revolution and Innovation (20162030)", which pointed out that by 2050, nuclear heating has the conditions for large-scale construction[2]. In 2018, the Energy Administration issued the "2018 Guiding Opinions on Energy Work" and the "Five Year Action Plan for Nuclear Energy Heating in the Northern Region", actively studying and promoting nuclear energy heating pilot projects in the northern region, and listing nuclear energy heating demonstration projects as key projects[3][4]. In 2021, the State Council issued the Action Plan for Carbon Peak by 2030, actively promoting advanced reactor demonstration projects such as High-temperature gas reactor, fast reactor, modular small reactor, offshore floating reactor, etc., and carrying out comprehensive utilization of nuclear energy [5], providing policy support for the in-depth expansion of nuclear heating in China.

2. Analysis of heating renovation methods

Nuclear heating mainly includes single nuclear heating and Cogeneration[6]. Single nuclear heating refers to the purpose of heating, which is usually realized by low-temperature heating nuclear reactor. During the heating period, the main mode of operation is heating, while during non heating periods, maintenance and shutdowns are carried out. Based on economic considerations, this type of unit can also be used for producing isotopes and other applications. Cogeneration refers to taking part of the heat from the steam turbine or pipeline of large nuclear power units as the heat source of urban heating to realize the co generation of heat and power loads.

For the traditional Cogeneration of thermal power units, steam extraction heating is usually performed by drilling holes in the connecting pipes between the intermediate pressure cylinder and the low-pressure cylinder of the turbine. The AP1000 nuclear power unit does not have an intermediate pressure cylinder, as shown in Figure 1. Steam can be extracted from the connecting pipeline between the high/low pressure cylinders, and pneumatic check valves and quick closing control valves can be installed on the extraction pipeline to prevent turbine overspeed and water inflow, while also regulating steam flow. Install a shut-off valve on the steam pipeline near the system reheat heater to provide shut-off and isolation. After steam extraction, the amount of steam entering the low-pressure cylinder decreases, which will correspondingly lower the inlet and outlet pressure of the low-pressure cylinder. Thermal power units generally install butterfly valves in the inlet pipeline of the low-pressure cylinder to regulate the extraction pressure and avoid affecting the safety of the last stage blades of the intermediate pressure cylinder. Generally, there is no

* Corresponding author: zhulingkai@woyoxin.com

regulating valve set. The low-pressure cylinder of the steam turbine in nuclear power units is equipped with a reheat regulating valve, which can be used for pressure control at the extraction port to ensure that the pressure of the high exhaust is always equivalent to the corresponding flow rate of the pure condensing load, in order to ensure the safety of the last few blades of the high-pressure cylinder.

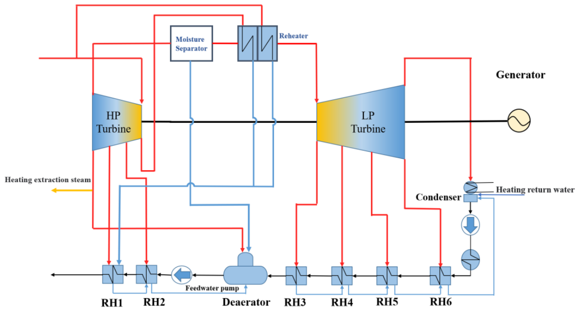

Figure 1. AP1000 secondary circuit schematic.

Due to the fact that the AP1000 unit does not have an intermediate pressure cylinder and an MSR is installed between the high and low pressure cylinders, the optional locations for steam extraction are either before or after the MSR, as shown in Figure 2. The steam after MSR is superheated steam, which causes more loss of available energy when used for heating; The steam before MSR is wet steam, which is closer to the heating parameters. Therefore, in the case of heating extraction without cascade utilization, the extraction port can be set in the pipeline before MSR, which is beneficial for the economic efficiency of the unit.

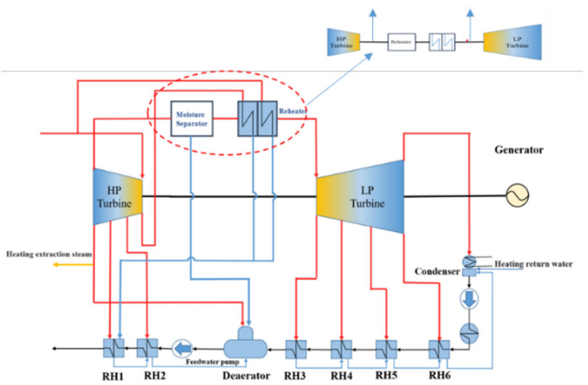

Figure 2. Schematic diagram of extraction position.

Low pressure cylinder zero output transformation technology and high back pressure transformation technology are two common transformation methods for traditional thermal power units. Both can improve the heating capacity of the original unit, but will correspondingly lower the power generation of the unit. Through analysis, it is considered that it is a feasible scheme to introduce heat storage device into the secondary circuit of Cogeneration nuclear power unit. In the heating season, the integrated heat storage device in the secondary circuit of the nuclear power unit of Cogeneration, as shown in Figure 3, is a way to improve the heat supply stability and load adjustment flexibility of the unit, which can achieve thermoelectric decoupling to a certain extent. Usually, heat storage devices can be arranged after the high discharge of the thermal system, in parallel with the heating network, without directly causing leakage of radioactive substances. This kind of heat supply transformation is based on Cogeneration of nuclear power units. By introducing a heat storage device, the heat supply capacity of the unit is improved, and the flexibility of heat and power load adjustment of the unit is also improved.

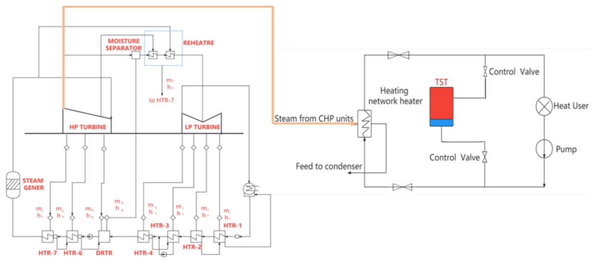

Figure 3. Cogeneration system with heat storage device.

3. Economic Analysis of Heating Transformation

3.1 Analyzing Economy from the Characteristics of Thermal System

Through the analysis of the heating renovation plan and related safety operation constraints for nuclear power units, taking the AP1000 pressurized water reactor as an example, a feasible heating renovation method is to extract steam from the high-pressure cylinder exhaust of the secondary circuit as a heat source, and conduct multi-stage heat exchange through the first station for internal heat exchange and the heat exchange station for external heating enterprises. Finally, the heat is transferred to the end user through the municipal heating network. Among them, the steam extraction diagram of the secondary circuit of the nuclear power unit is shown in Figure 4.

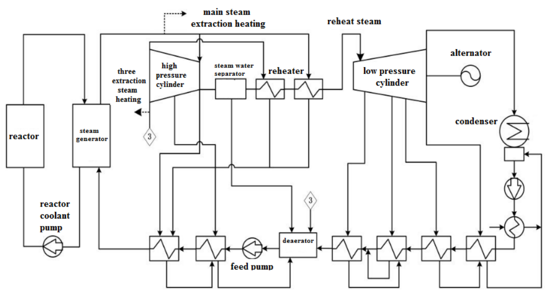

Figure 4. AP1000 unit extraction hydronics.

As shown in Figure 4, the secondary circuit system of nuclear power is composed of high-pressure cylinder, low-pressure cylinder, heaters at all levels, deaerator, condenser, etc. When the heating load is not large, the steam extraction volume is small. The new steam extracted from the main steam pipeline for heating will not have a significant impact on the primary circuit and power generation, and the transformation is simple, making it an acceptable method of steam extraction heating. However, with the increasing demand for heating, the method of extracting steam from the main steam is no longer applicable, and the economic efficiency of the unit is greatly affected.

The impact of extraction load on electrical power is basically linear. As the extraction load increases, the reduction in electrical power increases, and the impact of heating from the main steam extraction on electrical power is much greater than that of heating from the high exhaust extraction. Due to the extraction of steam from the main steam for heating, the new steam does not work through the turbine, while the high exhaust steam extraction for heating uses the steam that has been worked through the high-pressure cylinder for heating. Therefore, for the same heating load, the impact of high exhaust steam extraction heating on electrical power is smaller.

3.2 Analyze the Economy in Combination with the Spot Market

In combination with the time supply and demand relationship formed in the Spot market of Shandong electric power, the current time of use price of peak and valley electricity is optimized: from 12:00 to 13:00, the price of normal section is adjusted to the price of low valley electricity; 11: From 00 to 11:30, adjust the peak electricity price to the flat electricity price; 14: Adjust the electricity price from the flat section to the peak section from 30 to 16:00; The peak electricity price period implemented from June to August will be adjusted from 10:30 to 11:30 to 10:00 to 11:00; No adjustments will be made during other time periods. The adjusted peak valley time of use electricity price policy will be implemented from 2021.

A survey was also conducted on the electricity prices in Shandong Province, as shown in Figure 5.

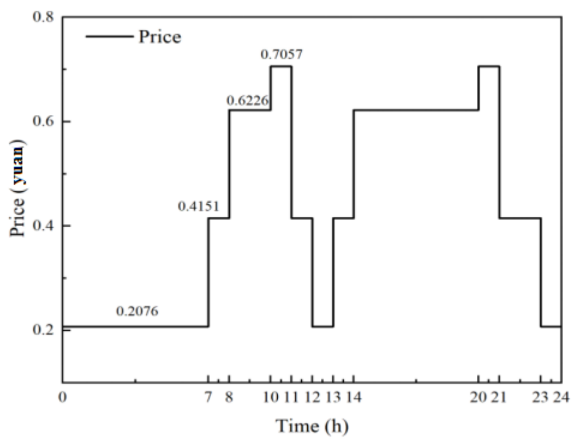

Figure 5. Real time electricity price situation.

Based on the analysis of the characteristics of peak and valley electricity prices in the electricity market, considering the introduction of thermoelectric decoupling into Cogeneration nuclear power units to realize the flexibility of unit load tracking, the corresponding benefits will be realized by realizing the adjustment of peak and valley electricity prices in the base load operation state of power generation.

4. Economic Evaluation of Cogeneration Nuclear Power Units

For the nuclear power unit of Cogeneration, if it can participate in the peak shaving of the power system through the secondary circuit heating and steam extraction adjustment, under the condition of comprehensive utilization of heat supply, the overall income formula of the unit can be expressed as generation income, heating income and peak shaving income. The specific calculation formula is shown in the following equation.

$$E = E_e + E_h + E_s \quad (1)$$

In the formula, E is the total revenue, E_e is the power generation revenue, E_h is the heating revenue and E_s is the peak shaving revenue.

The power generation revenue E_e can be represented by equations (2) to (4).

$$E_e = E_1 - E_2 \quad (2)$$

$$E_1 = \sum_1^{24} P_c \times L_1 \quad (3)$$

$$E_2 = \sum_1^{24} P_c \times L_2 \quad (4)$$

In the formula, E_1 is the adjusted electricity price benefits, E_2 is the electricity price gain without adjustment, P_c is the spot price, L_1 is the adjusted electrical load, L_2 is the electrical load when not adjusted.

The heating revenue can be specifically expressed as equation (5).

$$E_h = \sum_1^{24} P_h \times Q_h \times T \quad (5)$$

In the formula, P_h is the electricity price for heating, in yuan/MWh, Q_h is the real time heat load, in MW, T is time, in h.

$$E_s = \sum (P_i \times L_i) \quad (6)$$

P_i is the tiered electricity price, in yuan/kWh, L_i is the peak shaving amplitude, in kWh. When the unit tracks the load, it increases the power generation. When the value is negative, it decreases the power generation by tracking the load. As there is no relevant compensation mechanism for the participation of nuclear power units in peak shaving in the two detailed rules, the peak shaving benefits here are realized by tracking the peak and valley electricity prices of the units.

For Cogeneration nuclear power units, if the carbon emissions are calculated according to the same amount of power generation and heating, it can be predicted that it will be a huge economic benefit.

5. Generalize

The Cogeneration of nuclear power units meets the requirements of new power system construction, and has advantages such as clean energy saving. At the same time, it takes into account the feasibility of secondary circuit steam extraction adjustment to participate in power system peak shaving. The AP1000 nuclear power unit studied in this paper has a strong heating capacity and a large variable space for steam extraction, which provides

 https://doi.org/10.1051/e3sconf/202341601010

space for the expansion of the revenue space of Cogeneration nuclear power units. Analysis has found that changing the amount of steam extracted can lead to issues such as reduced electrical load or heat loss of the unit. The introduction of heat storage devices can better utilize the extracted steam and improve the flexibility of the unit. Nuclear power, as a clean and green energy source, does not generate carbon emissions and has significant environmental benefits. With the development of carbon emission indicators and carbon tax markets, it will mean corresponding new benefits.

References

1. Yujuan Wang, Xiaohua Niu, Xin Wang, etc. Research on the Statistical Indicator System of the Heating Industry [J]. District Heating, 2020, (4):56-67.
2. Ping Han, Jian Liao. Notice on Issuing the Action Plan for Energy Technology Revolution and Innovation (2016-2030) [J]. Petroleum and Petrochemical Green and Low Carbon, 2016, 1(04):54.
3. Hua Yao, Yun Huang, Jingying Xu, etc. Discussion on the Current Situation and Problems of Clean Heating Technology in Northern China [J]. Journal of the Chinese Academy of Sciences, 2020, 35(09):1177-1186.
4. Bin Zeng, Yanrui Li, Fanyu Qu, etc. Research on the Development Model of Nuclear Heating [J]. District Heating, 2022, (03):68-71.
5. Xinling Wang, Weishuai Wang, Haijing Zhang, etc. Actively responding to climate change and promoting clean and low-carbon transformation - Interpretation of the Action Plan for Carbon Peak before 2030 [J]. China's Electricity Industry, 2021, (12):22-25.
6. Xianhe Shang. The "dual carbon" goal promotes the development and application of nuclear heating [J]. China Energy, 2022,44(11):49-54.