Technical and Economic Analysis of Nuclear Heating Based on HPR1000

Qian Yu(✉), Jiang Hu, Lijuan Chen, Xin Shang, and Mei Rong

China Nuclear Power Engineering Co., Ltd., Beijing, China
437131329@qq.com

Abstract. HPR1000 is China's third-generation nuclear power technology with independent intellectual property rights, and is the main technology choice for the safe and efficient development and mass construction of nuclear power in China.

This paper investigated the situation of nuclear heating at home and abroad, combined with the demand of heating and steam supply, analyzed the market demand and commercial layout. The technical feasibility, safety reliability and economic suitability of HPR1000 heating and steam supply are studied and demonstrated. Through the analysis of typical cases, the research results show that the proposed scheme of heating system can meet the requirement of heat source reliability. By adding isolation between the secondary circuit and the heating system, the migration of radioactive materials into the heating system can be effectively prevented and the environmental safety impact assessment is acceptable. Through adaptive modification of the control system, automatic regulation of reactor, steam turbine and heating system can be realized to ensure the safe and reliable operation of the unit. In terms of economy, the economic benefits of HPR1000 heating can be competitive with coal, better than gas. The calculated price level of steam supply also has certain market competitiveness. It provides research support for the follow-up HPR1000 heating project.

Keywords: HPR1000 · Nuclear heating · Technical and economic

1 Introduction

Nuclear energy heating has been included in the national clean heating plan, nuclear energy steam supply and heating have been listed as encouraged industries by the state, and nuclear energy heating will become an important expansion direction for the comprehensive application of nuclear energy in the "14th Five-Year Plan" and in the medium and long term.

HPR1000 is a progressive third-generation nuclear power technology based on mature technology, with good maturity, and is the main technical choice for the safe and efficient development and batch construction of nuclear power in China. This paper investigates and understands the situation of nuclear energy heating at home and abroad, combines the domestic heating and steam supply needs, and analyzes the market demand and commercial layout. It provides a reference for the subsequent development and utilization of the heating market, especially the expansion of the application of HPR1000 in heating [1, 2].

C. Liu (Ed.): *Proceedings of the 23rd Pacific Basin Nuclear Conference, Volume 3*, SPPHY 285, pp. 225–232, 2023.
https://doi.org/10.1007/978-981-19-8899-8_23

2 Potential Market Analysis

Nuclear energy is a safe, reliable, clean and economical energy source. Worldwide, nuclear energy deserves to be more widely used because of its low resource consumption, low environmental impact and strong supply capacity. Exploring the use of nuclear energy to supply steam and district heat to industry and replace traditional energy combustion and heating is a potentially important way to reduce pollutant emissions, improve the atmospheric environment, and save energy and reduce emissions [3].

There is a large demand for heating in northern China, but the current heat source is mainly coal-fired, with the implementation of the national clean heating plan and carbon peak, carbon neutrality action plan, coal-fired heat source will gradually be replaced by low-carbon clean heat source [4]. Due to the difference in energy supply and heating time, the heat price varies greatly from place to place. For example, HPR1000 is built in the northern region, combined with the current long-distance heating technology, the market is easier to implement. With the increasing improvement of people's living standards, some conditional areas in the south also have heating needs.

China's industrial steam supply market capacity is large, and the users have a high tolerance of the industrial steam supply price. According to their different products, the acceptable steam supply price range is also large. In the economically developed southeast coastal areas, the price of industrial steam is generally 200–280 yuan/ton; in the southwest and northwest areas, the price of industrial steam is generally 100–150 yuan/ton.

At present, HPR1000 is mainly built in coastal areas. According to preliminary understanding, there are seven petrochemical industrial bases in coastal areas of China, of which the total amount of steam planned for the Lianyungang petrochemical base in Jiangsu Province exceeds 10,000 ton. It can be seen that the petrochemical industry base and the coastal area industrial base in China may serve as a potential steam supply market for HPR1000.

3 Technical Feasibility

The technical feasibility is mainly analyzed from the site layout requirements, the heating scheme feasibility, the feasibility of the key technology and the environmental safety impact.

3.1 Site Layout Requirements

Referring to the current level of long-distance heating technology, HPR1000 can heat urban areas within a distance of about 100 km in winter (the heating distance is not limited by heating parameters, but determined by the technical and economic feasibility of the heat network); Medium pressure saturated steam of about 2.5 MPa can be provided for users within a distance of 10 km, and low-pressure saturated steam of about 1.0 MPa can be provided for users within a distance of 40 km.

The special requirements of the layout of nuclear power plant sites make the problem that nuclear energy heating usually requires steam or hot water long-distance transportation is no longer a constraint, but the increase in the transmission distance will lead to an increase in the cost of heat network transportation, which will have a certain impact on the economy of nuclear energy heating projects, and the specific projects need to be determined in combination with technical and economic feasibility studies.

3.2 Heating Scheme

The heating medium of the urban heat network is usually high temperature hot water, and when HPR1000 is used, the heat source can be pumped by steam turbines. The steam turbine pumps steam into the heat grid heater to heat the circulating water of the heat grid, releases the heat to form a hydrophobic water, and the hydrophobic water is heated by the heat grid hydrophobic cooler after the condensate is heated, and finally sent back to the steam turbine condenser.

The HPR1000 heating system scheme is similar to the coal-fired cogeneration heating system scheme, and is consistent with the foreign nuclear power heating technology route, and the technology is relatively mature.

Due to the radioactive risk of HPR1000 secondary circuit steam in the event of SG heat pipe rupture accident, when HPR1000 is used to supply industrial steam, the secondary circuit steam cannot be directly used for external supply. The steam supply system is proposed to adopt steam conversion technology, using HPR1000 main steam to produce industrial steam through steam conversion equipment, and increase the isolation between the secondary steam and industrial steam. The technology has not yet been verified by the project, but it has been reviewed by domestic industry experts, believing that the technology is reasonable and feasible.

3.3 Feasibility Analysis of Key Technologies

The proposed heating system scheme study shows that it can meet the requirements of heat users for the reliability of heat sources; Through the adaptive transformation of the control system, the automatic adjustment of reactors, steam turbines and heating systems can be realized to ensure the safe and reliable operation of the unit; In terms of key heating equipment, the key heating equipment is heat network heater and heat network circulating water pump, which are widely used in conventional urban heating systems and have mature and reliable technology. The core equipment of the steam supply scheme is the steam conversion equipment, which usually includes superheaters, steam generators, hydrophobic tanks, feed water preheaters and feed water deaerators. After researching the mainstream potential equipment suppliers in China, there is no supply performance of large-scale steam conversion equipment, but the relevant equipment program research work has been carried out.

3.4 Environmental Safety Impacts

Since the pressure on the circulating water side of the heat grid is greater than the pressure on the auxiliary steam side, it is difficult for radioactive materials to enter the circulating water of the heat network under normal operating conditions, so the radioactive materials in the circulating water of the heating network are negligible, and the radiation impact on the heating user is negligible. In terms of steam supply, by adding the isolation between the second circuit and the heating system, it can effectively prevent the migration of radioactive materials to the heating system, and the environmental safety impact assessment is acceptable [5].

4 Economic Analysis

4.1 Economic Analysis of the Heating Scheme

According to the proposed design plan description, compared with the Pure Generator Set of HPR1000 in the heating plan, the first station of the supporting heat network and the conventional island steam extraction and transformation facilities have been added. At the same time, due to heating and steam pumping, some freshwater production facilities need to be added, and it is initially estimated that this part of the adjustment will cause the total investment to increase by about 300–500 million. Due to the impact of the site conditions, the total investment of the construction project varies greatly in the cost of earthwork, roads and drainage projects. Referring to the current cost level of the HPR1000 nuclear power unit under construction in China, considering the impact of site differences and the limitation of the depth of the scheme, the total investment of the proposed plan corresponding to the HPR1000 pumped steam heating is about 43 billion to 45 billion yuan (the investment does not include the heat network transmission and distribution part, and the boundary is the plant wall) [6].

There are seven petrochemical industry bases in China's coastal areas, among which the total amount of steam planned for the petrochemical base in Lianyungang Petrochemical Base in Jiangsu Province exceeds 10,000 tons, and the area has a certain scale of heating demand. Therefore, the economic analysis of this part assumes that the construction site of a nuclear power project is located in the coastal area of Jiangsu Province, Jiangsu Province belongs to the economically developed area, the industrial demand is strong, and its coal-fired benchmark electricity price is at the national median level, which has a certain representativeness [7].

The economic analysis part is mainly based on the conclusions of the financial evaluation, and the national economic evaluation is not considered for the time being. According to the proposed plan, the market competitiveness is judged by measuring the price of the product.

- Proposed design input main parameters:

  Electrical rating: 1200 MWe.
  The annual heating capacity of the two units: 1092×106 GJ/year.
  Heating and steam extraction leads to a decrease in power generation: 122 MWe.
  Annual water consumption: 25 ten thousand tons.

- Main parameters of financial analysis:

  Construction investment: 17,000 yuan/kW (the completed price investment is about 41 billion yuan, Excluding the deductible VAT during the construction period).

Return on capital: 8%.
Other parameters: Same as the HPR1000 conventional generator set.

- Estimated results:

Taking the current coal-fired benchmark electricity price of 391 yuan/MWh (including tax) in Jiangsu Province as the input parameter, under the premise of ensuring the rate of return on project capital of 8%, the calculated unit price of heating is about 44 yuan/GJ, which is close to the heat price of coal-fired units (which is inferior in the market price range) and better than the gas heat price。If the current heat price is reduced by 20% to 35 yuan/GJ, the electricity price needs to rise by 1.65% (397.5 yuan/MWh) or increase the annual utilization hours by 1.78% (7125 h/year), which is very competitive compared with the traditional coal-fired heating supply. For regional project construction with a coal benchmark price higher than 397.5 yuan/MWh, it also has a high market competitiveness.

4.2 Economic Analysis of Steam Supply Scheme

According to the proposed design plan, compared with the HPR1000 pure generator set, the steam supply scheme adds steam conversion stations and conventional island steam extraction and transformation facilities. At the same time, due to the large steam supply, it is necessary to increase some freshwater production facilities (seawater desalination, etc.), and it is initially estimated that this part of the adjustment will cause the total investment to increase by about five hundred million to 1 billion yuan [8]. Due to the impact of the site conditions, the total investment of the construction project varies greatly in the cost of earthwork, roads and drainage projects. Referring to the current cost level of the HPR1000 nuclear power unit in China, considering the impact of site differences and the limitation of the depth of the scheme, the total investment of HPR1000 steam supply corresponding to the scheme described is about 43.5 billion to 45 billion yuan (the investment does not include the steam transmission and distribution part outside the plant, and the boundary is the plant wall).

It should be noted that, due to the depth of the programme, this level of investment is a preliminary estimate of the proposed programme. The impact of the heating and desalination scheme on the scale and design scheme of the original nuclear island, conventional island and BOP of the nuclear power plant is not considered, and the costs related to the control of the reactor under the heating scheme are not considered. In addition, the investment in heating and steam supply related facilities and supporting water production facilities will also change accordingly with the adjustment of the heating scale.

Financial evaluation:

- Proposed design input main parameters:

Electrical rating: 1200 MWe.
The annual steam supply capacity of the two units: 4.8 million tons/year.

Heating and steam extraction leads to a decrease in power generation: 175 MWe.
Annual water consumption: 4.88 million tons.

- Main parameters of financial analysis:

Construction investment: 17,000 yuan/kW (the completed price investment is about 41 billion yuan, Excluding the deductible VAT during the construction period).
Return on capital: 8%.
Other parameters: Same as the HPR1000 conventional generator set.

- Estimated results:

Taking the current coal-fired benchmark electricity price in Jiangsu Province 391 yuan/MWh (including tax), 410.6 yuan/MWh (up 5%), 371.5 yuan/MWh (5% down) as input parameters, under the premise of ensuring the return on project capital of 8%, the calculated unit price of steam supply is about 134 yuan/t, 76 yuan/t, 191 yuan/t (the calculated steam supply price is the factory price, excluding the pipeline network transmission and operation and sales parts). According to relevant surveys, in the economically developed areas of the southeast coast, the terminal price of industrial steam is generally 200–280 yuan/ton. Judging from the calculation results, under the premise of ensuring a reasonable transportation distance, the steam price has a strong market competitiveness in the southeast coastal area. Electricity price goes down by 1% (387 yuan/megawatt hour), and the steam price will increase by 8% to 145 yuan/t, which still has a certain market competitiveness compared with the current market price. For regional project construction with a coal-fired benchmark price higher than 391 yuan/MWh, it has high market competitiveness and good economic benefits.

4.3 Brief Summary

According to the design plan, the main output product of the heating project is electricity, and the output of heating products leads to a small proportion of power generation reduction, of which the reduction of steam supply power accounts for 7.30% of the total power, and the reduction of heating power accounts for 5.08% of the total power. Therefore, the change of electricity price is very sensitive to the unit price of heating products, and the results of financial analysis can also be verified that the fluctuation of electricity prices has a very large impact on heating products. If the electricity price rises by 1.65%, the unit price of heating drops by 20%.

The unit price of heating products in this paper is calculated under the premise of ensuring the return on project capital of 8%, and the LPR has been declining in the form of the recent decline. If the project return rate can be accepted by 7%, under the same parameter, the estimated unit price of heating is about 25 yuan/GJ, the unit price of steam supply is about 90 yuan/t (including tax), the unit price of heating can be greatly reduced, heating and steam supply will have a very strong market competitiveness.

It should be noted that the above economic analysis conclusions are based on the calculation results of specific schemes and specific conditions, and the heat price and industrial steam price of the current market are generally linked to the price changes in the coal-fired market, and the calculation does not consider the impact of the transmission and distribution network. Therefore, nuclear energy heating is generally feasible, but the landing of specific projects also needs to be further analyzed in combination with the site conditions and heating environment.

It is worth noting that under the new normal of the economy, China's overall economy has changed from high-speed growth to medium-high-speed growth, the level of interest rates has been declining, and the investment income of various industries has also shown a downward trend, and investors are bound to lower the expected yield in the future. The economic evaluation and calculation period of nuclear power heating projects is only 30 years, while the design life of the third generation nuclear power plant is 60 years. Therefore, if the overall economic environment and the complete operation period of nuclear power plants are considered, the actual economic benefits of nuclear energy heating will be better than the calculated economic benefits, the profitability will be stronger, and it will have better economic feasibility [9, 10].

5 Conclusions

From the perspective of technological innovation, nuclear energy heating is the comprehensive development and innovative utilization of nuclear energy.

From the perspective of economic development, nuclear energy heating projects can provide employment opportunities for tens of thousands of people during the construction period, which will further promote the development of local transportation, communications, building materials, education and other municipal facilities and welfare services, and is of great significance to accelerating local economic development.

From the perspective of environmental protection, nuclear energy heating projects have significant environmental benefits in reducing sulfur dioxide, carbon dioxide and nitrogen oxide emissions, and are an important direction for building a low-carbon energy system.

It can be seen that under the set boundary conditions, the construction of nuclear heating project is feasible and the economy is acceptable. However, if the boundary conditions change greatly, coupled with the influence of the supporting pipe network and other factors, the specific project also needs to be further analyzed and calculated combined with the plant site conditions and the heating environment.

References

1. IAEA: Market Potential for Non-electric Applications of Nuclear Energy (2002)
2. International Energy Agency: Nuclear Power in a Clean Energy System. IEA Publications, Vancouver (2019)
3. Leurent, M., da Costa, P., Rämä, M.: Cost-benefit analysis of district heating systems using heat from nuclear plants in seven European countries. Energy **149**, 454–472 (2018)
4. Li, Y., Bai, Y., Han, S.: Analysis of current status and development trend of nuclear district heating. Progress Report on China Nuclear Science & Technology, vol. 6
5. VisualAir. 2019 World air quality report: Region & city PM2.5 ranking (2019)

6. Wang, J., Dai, Z., Xu, H.: Research status and prospect of comprehensive utilization of nuclear energy. Bull. Chin. Acad. Sci. **34**(4), 460–467 (2019)
7. Cholewinski, M., Tomków, Ł: Modeling of a nuclear combined heat and power station supplying heat to remote municipal customers: the case of Poland. J. Power Technol. **98**(3), 255–266 (2018)
8. Yan, Y., Tian, J., Cai, Q.: Technical and economic analysis of deep pool reactor district heating. Gas Power **13**(4), 47–53 (1993)
9. Hao, W., Zhang, Y.: Research and development of NHR200-II. China Nucl. Power **12**(5), 518–521 (2019)
10. IAEA: Guidance on Nuclear Energy Cogeneration. IAEA, Vienna (2019)