Research on the Coordinated Operation Mode of Nuclear Power in the Evolution of High-Penetration New Energy Power System

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Abstract. With the large-scale intermittent new energy integration into the power system, the safe and stable operation of the power grid faces huge challenges. Nuclear power output is stable and the inertia is large, which can provide the necessary power, electricity and inertia support for the power system with a high penetration of new energy integration. This paper comprehensively considers various factors such as China's energy resource conditions, environmental constraints, demand pattern, development schedule, construction cycle, and faces the development scenario of power systems with different penetration of new energy integration for medium and long-term construction. The regional power grid proposes a coordinated development strategy for nuclear power and other new energy that meets the requirements of power system safety and stability, energy conservation, and emission reduction, and provides a useful reference for the healthy development of China's future nuclear power and new energy industries.

1. Introduction

The report of the 19th National Congress of the Communist Party of China proposed "promoting the revolution in energy production and consumption, and building a clean, low-carbon, safe, and efficient energy system", which pointed out the direction of China's energy industry development for a long period of time. As an important clean energy source, nuclear power plays an important role in building a new energy system in China. Especially for the economically developed areas in the central and eastern regions of China, where energy resources are relatively scarce, making good use of the resources of the nuclear power plant site, and actively developing nuclear power are effective ways to increase the regional energy self-sufficiency rate and ensure energy security.

From the perspective of power system development, with the rapid progress of new energy power generation technology, the penetration of intermittent new energy power generation will be further increased, which brings a series of challenges to the safe and stable operation of the power grid. The nuclear power output is stable and the moment of inertia is large, which is suitable for bearing the base load of the power. At the same time, it provides the necessary inertia for the system and plays the role of the power support of the end grid, which is more conducive to the consumption of intermittent power sources such as wind power and solar power. Therefore, there is an urgent need to deeply study the coordinated development strategy of nuclear power and other various power sources, including intermittent power sources such as wind power, solar power generation, and energy storage methods,
which can meet the requirements of energy-saving and emission reduction and adapt to the safe and stable operation of the power system. The coordinated strategy development of nuclear power can effectively reduce the cost of electricity for society, promote the construction of national ecological civilization, and improve people’s living standards[1-3]. This paper comprehensively considers various factors such as China's energy resources conditions, environmental constraints, demand patterns, development schedule, construction cycle. A scenario for mid-to-long-term development of power systems with different penetration of new energy integration is built, and a regional power grid with high nuclear power installed capacity in China is selected as the target. We have analyzed the impact of nuclear power and other power sources participating in power grid peak shaving in different ways on new energy consumption and the economics of system operation and puts forward strategic suggestions to promote the coordinated operation of nuclear power and new energy. The research results will provide decision-making support for promoting the orderly and healthy development of China's nuclear power and new energy, and further promoting energy transformation.

2. Scenario Study with Different Penetration of New Energy

High-quality energy development requires a higher level of clean and low-carbon energy transformation. The key lies in solving the problems of optimal allocation and coordinated development of scenery, nuclear power, various power sources, and flexible adjustment of resources. The balance characteristics and methods of the high-rate new energy power system have changed significantly, and the efficient use of nuclear power is facing new challenges [4,5]. In 2017, some nuclear power utilization hours were affected, with utilization rates below 70%. This is closely related to the operating characteristics of new energy. The strong temporal and spatial differences in power fluctuations of new energy generation make it increasingly difficult for the power system to maintain the temporal and spatial balance, and the problem of lack of flexibility to adjust resources is becoming increasingly prominent.

In order to study the development scale of nuclear power under different new energy penetration rates and the coordinated operation with new energy, it is necessary to optimize the typical areas where nuclear power and new energy power generation have great development potential. This paper determines the typical areas based on the following basic principles: (1) There should be enough space for electricity demand; (2) It is more urgent to increase the penetration of clean energy power generation; (3) It has abundant nuclear power plant site resources; (4) The power grid structure has a good foundation. Comprehensively considering the above four principles, this paper selects a regional power grid in China as a typical area for research.

Based on the source-grid-load-storage coordinated planning theory and relying on the power system planning software GESP with independent intellectual property rights (as shown in Figure 1), it meets the constraints of non-fossil energy consumption ratio, power balance, peak shaving, etc. Under the premise of constraints, with the goal of the lowest total cost of power supply in the whole society, we will simultaneously optimize the development scale and location of various flexible adjustment resources such as nuclear power, new energy and pumped storage, gas power, and thermal power flexibility, as well as the flow and scale of power.
Multi-region and multi-scenario Power planning model

Current status and development of power grid

Power supply status and development

Endowment of power generation energy resources

Power pattern

Power flow scale and direction

Operating statistics

Power transmission technology

Economy

Energy power Development policy

Figure 1. The medium-and-long term power system planning model

From the simulation results, under the baseline scenario [6], the total scale of various power installations in the target area is about 520 million kilowatts in 2035, accounting for 15.6% of the total installed capacity of the country, of which nuclear power accounts for the highest penetration, about 46.7%; The total installed capacity of wind and solar energy power generation is about 160 million kilowatts, accounting for 31.5% of the total installed capacity, and power generation accounts for 12.7% of the local electricity demand. Based on the baseline scenario, comprehensively consider the new energy resource potential, environmental endurance, technological progress and other factors in the target area, constrain the hydropower and external calls to remain unchanged, consider the doubling of local new energy installations, and build the target area by 2035 High penetration of new energy access scenarios.

Figure 2. Installation of new energy access scenarios with different penetrations in the target area

Under the scenario of a high percentage of new energy access, the total installed capacity of various power sources in the target area will be approximately 640 million kilowatts in 2035, of which new energy installed capacity will reach 320 million kilowatts, accounting for 50% of the total installed capacity of local power sources. Under this scenario, huge environmental benefits will be generated, with an average annual reduction of 2.06 million tons of carbon dioxide, 52,000 tons of sulfur dioxide, 4,448 tons of nitrogen oxides, and 4,469 tons of soot.

However, while increasing cleanliness, due to the large penetration of new energy access, it will occupy the space of conventional power sources such as coal, gas and nuclear power, and coal, gas, and nuclear power will be reduced by 37 million kilowatts, 6.5 million kilowatts and 1500 respectively. Ten thousand kilowatts; on the other hand, in order to meet the system power balance and peak shaving needs, it is necessary to add 2.8 million kilowatts of pumped storage and electrochemical energy storage and 22.4 million kilowatts respectively. In this way, considering only the planning
level, when the cost of energy storage is reduced to 3500 yuan/kW, a new system cost of 458.3 billion yuan is still required.

3. The coordinated operation mode of nuclear power and new energy
For the coordinated operation of nuclear power and new energy, this paper considers the randomness and uncertainty brought by the high penetration of new energy grid connection, as well as the random failure of the unit and the randomness of the power load, using the random production simulation software of power system developed by ABB GridView, a simulation analysis of a large regional power grid in China in 2035.

![Figure 3. Power system stochastic production simulation model](image)

A week with the largest penetration of new energy power generation (about 14%) is selected as a typical week, and there is basically no wind and light phenomenon through flexible power regulation such as pumping and storage. At this time, nuclear power does not participate in peak shaving. For the typical week, other conditions remain unchanged, assuming that the installed capacity of new energy is doubled, and the penetration of power generation is increased to 25% overall. If nuclear power still does not participate in peak shaving, wind and light will be abandoned, and the amount of power is about 540 million kWh. The rate of abandoned electricity is about 5.6%. However, if the operating mode of nuclear power is adjusted to allow 20% of its installed capacity to participate in peak shaving, it can reduce the amount of abandoned electricity by about 180 million kWh, and the amount of abandoned electricity drops to 3.7%. On the other hand, as shown in Figure 4, in the future high-penetration new energy power system, with flexible resources complementing the "short board" and energy storage and other technological advances, nuclear power is only a supplement to the lack of peak shaving resources during the necessary period.
4. Conclusion

From a technical point of view, nuclear power and new energy can achieve an optimized operation through a coordinated operation. On the one hand, nuclear power moderately participates in grid peak shaving, that is, during new energy abandonment concentration periods, peak shaving depth is controlled within 20% for day-to-day regulation, which can promote the consumption of new energy without excessively increasing costs. On the other hand, the participation of nuclear power in peak shaving should be based on the overall situation of the system. There is a "reasonable value" with the best economic efficiency for the level of new energy consumption. If one-sided pursuit of low curtailment of the new energy will greatly improve the system peak shaving cost, and reduce the overall economy of the system. At this stage, improving the depth of thermal power peak shaving through flexibility transformation is better than that of nuclear power participating in system peak shaving, and nuclear power can compensate thermal power with deep peak shaving through the auxiliary service market to achieve optimal economics. With the advancement of energy storage technology in the future, the joint operation of nuclear storage will provide more options and space for the coordinated development of nuclear power and new energy.

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