Research on the Prospect of Nuclear Power Development in Mid-and-Long Term

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Abstract. To study the fundamental function and developing orientation of nuclear power in China, it is of great significance to grasp the fundamental requirement of high-quality energy development under the new energy security strategy of “four revolutions and one cooperation”. Based on the development trend of nuclear power at home and abroad, this paper analyzes the development prospects of nuclear power and the overall positioning in China's energy and power system, combined with the cross-border integration of digital revolution and energy revolution, and proposes the future development and potential innovation direction of the nuclear power industry.

1. Introduction
In the context of the common response of humankind to global climate change, the clean and low-carbon transformation of energy has become a global trend. Renewable energy has entered an era of large-scale development, and the future development of world nuclear power is affected by the Fukushima nuclear accident in Japan. The future trend is full of uncertainties. From a global perspective, major changes have taken place in the world's energy supply and demand pattern. The energy production center is tilted westward and the consumption center is moved eastward. Energy geopolitics is undergoing profound changes. Energy production and the interests of consumer countries are being divided and adjusted[1]. Under the superposition of various uncertain factors, the decision-making of nuclear power development in various countries is becoming more conservative. Relatively speaking, in the recent period, China's nuclear power development opportunities are greater than challenges. Under the overall strategic location of accelerating the construction of a clean, low-carbon, safe and efficient energy system, it is of great significance to plan for the development of nuclear power in the new era. This requires firmly grasping the fundamental requirement of high-quality energy development under the new development concept.

2. Nuclear power development trends
Nuclear energy is one of the important measures to promote the clean and low-carbon transformation of global energy. Since the first civilian nuclear power in the Soviet Union in 1954, nuclear power has developed rapidly worldwide. Especially in the 1970s and 1980s, nuclear power gradually became a symbol of a country's industrialization and modernization. According to the latest statistics from the International Atomic Energy Agency, as of June 2019, there were 449 nuclear power generating units in operation worldwide with a total installed capacity of approximately 398 GW, and 54 nuclear power generating units under construction with a total installed capacity of 0.55 GW. Although Germany,
Switzerland and other countries have made the decision to abandon nuclear for safety reasons, there are still many countries in the world who believe that nuclear power is a mature, clean, dispatchable and economic technology, which is strengthening local energy supply. It will play an important role in the process of security and mitigation of climate change. Among them, developing countries still have a strong desire to develop nuclear power. Of the 54 units under construction worldwide, 83% are concentrated in developing countries.

As the largest developing country, the scale of nuclear power under construction in China has been the first in the world for a long time. Since the 13th five year plan, affected by the policies, the number of nuclear power put into operation every year has some volatility, but the overall healthy development trend has been maintained. In 2018, a total of 7 units were put into commercial operation. As of June 2019, there were 46 nuclear power units in operation in mainland of China, with a total installed capacity of 42.85 GW, surpassing Japan and ranking third in the world [2,3].

From the perspective of the energy strategies of various countries, the development positioning of nuclear power is closely related to the national strategy and energy strategy. Different strategies have different weights for power attributes or nuclear attributes. Russia is one of the earliest countries in the world to use nuclear energy, taking into account nuclear power and military use, and its technological advantages have been maintained from the Soviet period to the present, and it has a considerable strategic vision. France’s long-term adherence to the nuclear energy-based energy development strategy has effectively alleviated energy security issues and supported the country’s economic development with lower electricity prices.

Judging from the predictions of the future development trend of nuclear power by major energy institutions, they are basically cautiously optimistic. The reason for the caution is still the safety factors of nuclear power. Safety has always been the central point of nuclear power development. Affected by these related factors, the development of global nuclear power is highly uncertain. The International Atomic Energy Agency (2017) made high and low scenarios for global nuclear power development by 2050, with 345 GW to 554 GW in 2030, 332 GW to 717 GW in 2040, two scenarios. The results vary greatly, and even the low level of program development is not as good as the current one. Relatively speaking, IEA (2017) and BP (2018) remain optimistic and predict that the global nuclear power development scale will be between 490-720 GW by 2040.

China's nuclear power industry has a good foundation for development and has the conditions to plan for future development from a global perspective and a more strategic position. First of all, China is one of the few countries in the world that has a relatively complete nuclear power industrial system, and major breakthroughs have been made in the autonomy and localization of key equipment and materials. Secondly, China's 46 units that have been put into commercial operation have outstanding performance in safe operation, and their main operational technical indicators remain at the forefront of the world. They have accumulated rich experience in industry management, security, and emergency response. Third, the nuclear power industry chain is long and has a strong driving force. Finally, China’s nuclear power industry has good prospects for going global, and its potential development market is broad.

3. Research on the Scale and Location of Nuclear Power Development in China

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), this paper meets the constraints of non-fossil energy consumption ratio, power balance, peak shaving balance, 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, as well as the direction and scale of power flow.

It can be concluded from the simulation results that China's nuclear power installed capacity has maintained rapid growth. For the baseline scenario [4], the installed capacity of nuclear power will be 150GW in 2035 and 335 GW in 2050 respectively, which means there will be 6 added units being put
into commercial operation every year until 2035, and 10 added units being put into commercial operation every year from 2035 to 2050. The majority of nuclear power plants are still located in East China, South China, and North China. In 2035, the total nuclear power of the three regions accounted for 87% of the whole country. With the expansion of nuclear power construction inland in 2050, the total proportion of nuclear power in the three regions has declined, but it still accounts for more than 70% of the national nuclear power.

In general, the stable and healthy development pace of nuclear power in the medium and long term plays a key role in China’s energy security and green transformation, and can become a problem-solving variable in the Energy Impossible Trinity [5,6]. China’s energy resources are relatively scarce, and the external dependence of oil and gas continues to rise. Nuclear power is an important choice for local energy security in meeting various technological routes for green and low-carbon development. In the short term, the development of nuclear power to a certain extent realizes the stock and incremental replacement of oil and gas resources, which can reduce the import demand; in the medium and long term, the depletion of traditional energy has become a general consensus, and energy security will depend on technological competition in the field of new energy. It is of great significance that the nuclear power industry can effectively reduce costs and improve efficiency. The next step should be to accelerate the standardization, autonomy and serialization of nuclear power construction, strengthen the project management of project construction, strive to reduce the kilowatt investment of nuclear power units, and enhance the economic competitiveness of nuclear power.
4. The potential innovation direction of the nuclear power industry in line with the digital energy economy

Adapting to the requirements of high-quality energy development and creating a nuclear power innovation-driven development model, we are also facing a significant historical change trend of the cross-border integration of the energy revolution and the digital revolution [7,8]. Since the new century, the rapid development of energy and power technologies has been continuously integrated with modern information communication and digital technologies such as "big cloud moving intelligence", which has promoted profound changes in terminal energy consumption. The bigger background is that at present and for some time to come, the new and old kinetic energy of China's economy has been profoundly transformed, and the Industrial Internet has become the core field of China's implementation of network power and Industry 4.0. In 2019, the Central Economic Work Conference listed the promotion of high-quality manufacturing as the top of seven major tasks this year, and clearly proposed to accelerate the construction of new infrastructures such as artificial intelligence, industrial Internet, and the Internet of Things.

The deep integration of industrial experience with a new generation of artificial intelligence, and extensive external empowerment with the help of giant collaborative networks, has become the core path for future technological competition and enterprise innovation and development [9]. Siemens, AVIC, Tencent and other companies all regard the development of industrial Internet platforms as their core strategy. First, the Industrial Internet has become the main battlefield after the consumption of the Internet. The data shows that the scale of China's industrial Internet direct industry is about 570 billion yuan, with an average annual growth rate of up to 18%, and it will reach trillion yuan by 2020. Second, the Industrial Internet has become a key area that affects the global competition landscape. "German National Industrial Strategy 2030" even directly called on Europe to reverse the deindustrialization trend, and the German national level should directly participate in promoting the development of the platform economy [10]. The third is to look to the future. Whether or not you have an industrial Internet platform determines whether an enterprise can evolve to the next generation of enterprise organization and become an enabling platform enterprise, at the top of the ecological chain.

Nuclear power, as the model of modern industry, has unique and irreplaceable advantages in technology and management, which is very potentially competitive in the construction of the industrial Internet. As China's industrial Internet pioneer, Aerospace Cloud is mainly based on the advantages of informatization and intelligent manufacturing, empowering the majority of small and medium-sized enterprises, continuously forming new formats and models, and significantly improving the quality of enterprise development. The current stage is a key window period for the location of the future national industrial Internet main platform. The new generation of information technology and the transformation of various industries are accelerating integration, and the competition and cooperation of different types of industrial Internet platforms will gradually deepen. The future strategic
competition is manifested by the network location, enabling path and core technical strength, and the nuclear power industry has similar or unique features. The nuclear power industry, as a hugely complex system with a lot of high-techs, could be the resource collaboration platform and innovation platform throughout the upstream and downstream of the industrial chain, empowering the SMEs and leading them towards Industry 4.0.

5. Conclusion
In summary, to meet the general requirements for high-quality energy development, nuclear power needs to embark on a road of innovation, coordination, greenness, openness, and sharing, and actively assume the basic functional role of national competitiveness. First, nuclear power is an important part of China's non-fossil energy supply system. It plays an important role in deeply replacing conventional fossil energy and continuously optimizing the energy supply structure. It is also an important aspect of China's efforts to create a green and low-carbon international competitiveness. The second is that nuclear power is a strategic choice to efficiently meet energy needs and ensure national energy security. Third, the development of nuclear power is an important support for enhancing the international competitiveness of China's equipment manufacturing industry, developing and supporting the status of China's nuclear power. Fourth, nuclear power can play an important role in the construction of the “Belt and Road” and form greater competitiveness under open conditions. Fifthly, in the digital energy economy, extensive external empowerment will drive all parties in the society to share development.

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