Technical Requirements Analysis of Power Grid Development for High Proportion of Renewable Energy

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Abstract. At present, China's energy and power system is in a critical period of upgrading and transformation, and new energy power generation will occupy an increasingly important position in the energy field. In the future, new energy will be connected to the power grid on a large scale, which will bring challenges to the safe, stable and efficient operation of the power grid. Therefore, it is necessary to cultivate corresponding technologies to support the future development of the power grid. This paper starts with an analysis of China's energy transformation vision, clarifies the many challenges that the power grid will face, and then proposes five key technical requirements for the future development of the power grid.

1. Introduction
At present, the global response to climate change is accelerating, resources and environmental constraints are continuously strengthened, energy development faces new situations and new challenges, the world's energy landscape is deeply adjusted, and resources development and utilization methods and energy utilization levels are undergoing profound changes. As an important foundation to support the modern economic system, the upgrading and transformation of the energy and power system will directly affect the sustainable development of China's economy and society and China's competitiveness in the new round of global industrial transformation. Therefore, it is imperative to build a new generation of energy systems that meet the requirements of China's energy transformation to achieve a clean, low-carbon, safe and efficient energy supply.

In the realization of China's energy transformation, the power system will play an irreplaceable role. Therefore, it is necessary to clarify the future national power structure and development layout of China's energy transformation pattern and grid development challenges, and then put forward the key technology requirements for grid development oriented to high proportion of new energy access.

2. China's energy transformation prospects
According to the research on the development prospects of various power sources, in 2020, 2025 and 2035, the installed capacity of power sources in China reached 2.11 billion, 2.74 billion and 3.88 billion kilowatts, of which non-fossil energy accounted for 41% in 2017 and increased to 43%, 49% and 60%. The installed capacity of new energy such as wind power and solar power will increase rapidly, and
thermal power will still maintain a certain scale, but it will gradually shift from the main body of electricity supply to the main body of power supply.

The blueprint for the future development of the new generation of power system and the key technological approaches are clearly oriented, that is, to increase the proportion of new energy, to strengthen the capacity of energy allocation and transmission, and to optimize the way of energy utilization. The layout of future power development and power flow are shown in Figure 1.

![Figure 1. Overall power supply development layout and power flow direction](image)

In the new development situation, in order to meet the resource endowment conditions and economic and social needs of our country, the future power grid will be integrated with distributed power, energy storage, integrated energy systems, advanced information and communication technologies, and further extended into flexible and efficient wisdom. The energy network will provide safe, reliable, efficient and diversified energy supply, and provide strong support for building China's modern economic system.

3. Power grid development challenge
Looking into the future, the profound changes in the way energy and energy production and consumption bring a series of major challenges to the power grid, mainly reflected in the following four aspects:

(1) High proportion of new energy, power grid balance adjustment capability needs to be enhanced

China's new energy output and load demand have reverse distribution characteristics in both time and space dimensions, and the proportion of new energy access is greatly increased, which will bring severe challenges to the balance adjustment capability of the power grid. First, the issue of new energy power balance is prominent. Second, the system's dynamic adjustment capability needs to be strengthened.

(2) The shape of the power grid changes, and the safe operation presents new features

With the rapid development of new energy and direct current transmission, power electronics technology is widely used, and the shape and operation characteristics of the power grid have undergone profound changes. First, new problems in the safe operation of the system are highlighted, and the difficulty of safe operation is increased. Second, the system operation characteristics change, and the flexible control requirements are further improved.

(3) The power reform is deepening, and the institutional mechanisms need to be improved
In the past two years, the cost of new energy development and utilization has continued to decline. The National Development and Reform Commission and the National Energy Administration have also introduced a number of policies in promoting new energy consumption and promoting affordable Internet access. However, compared with conventional power sources, the cost of new energy power generation is still high. Our country’s renewable energy subsidies have experienced funding gaps and the effective price incentive mechanism for thermal power to participate in peak shaving, energy storage technology development, and power load participation system adjustment has not yet been formed, and the accuracy of policy and market design needs to be improved.

In short, in the context of energy change, the opportunities and challenges of the grid coexist. From the perspective of the external environment, the in-depth advancement of energy transformation poses new challenges to the functional form and operation mode of the power grid; in terms of internal factors, high proportion of new energy brings greater risks and impacts to the power grid. As a result, higher requirements are placed on the technical requirements for the development of the power grid.

4. Power grid development technology requirements

Focusing on the construction of a clean, low-carbon, safe and efficient energy system, based on China's energy development status, it is necessary to focus on the following five major fields of major technical areas that have a global impact on grid development:

4.1. Efficient, low-cost, long-life energy storage technology

Energy storage can fundamentally change the operation mode of the traditional grid “real-time supply and demand balance” and enhance the flexibility of the power system, which is an important support for the power grid. China's energy storage development is still in the cultivation stage. The engineering application still takes the transition from experimental demonstration to commercial operation as the main goal.

High safety, long life, high efficiency and low cost are the overall goals of energy storage technology development. It is expected that the energy storage will be initially commercialized in 2035, and the energy storage technology with independent intellectual property rights will be fully applied in the field of safe operation of the power grid to improve the compatibility and acceptance of the power grid.

At present, in order to meet the development needs of the new generation of power system, the key problems to be solved urgently in the field of energy storage are to enhance and improve the energy density, power density, response time, energy storage efficiency, cycle performance, economy and reliability of energy storage devices. Technological research is needed in battery materials, manufacturing process, system integration and operation and maintenance.

4.2. High reliability and low loss power electronics

The wide application of high-performance power electronics technology can significantly improve and realize the controllability of the generation, transmission, distribution and use of power systems, and is an important guarantee and basic condition for realizing the safe and stable operation of the power grid. At present, China still has a large gap between the manufacturing technology of power electronic devices and the international advanced level.

In terms of wide bandgap power electronic devices, there are many problems in material and process, such as complex manufacturing and many difficulties in the new DC transmission and DC networking technology. In our country, the device design, manufacturing and test technology still need to be strengthened, and the key technologies need to be developed independently.

High reliability and low loss are the overall goals of future development of power electronics technology. It is necessary to further increase investment in research and development, and promote the autonomy, controllability and safety of the devices, thereby improving the efficiency and reliability of power transmission and increasing the capacity of the power grid. In the aspect of wide bandgap power electronic devices, the application research of silicon carbide (SiC) devices and their applications in electrical devices such as switching devices have been promoted, and basic theoretical research on
Gallium nitride (GaN) materials has been carried out, and related switching devices have been developed. In the new DC transmission and DC grid technologies, the research focuses on the research of transmission technology such as capacitive commutation HVDC transmission technology, compact converter station technology and multi-terminal HVDC transmission technology, and promotes the realization of multi-gigawatt-level voltage source commutation HVDC transmission and its demonstration engineering application in large-scale power grid access.

4.3. High strength insulation technology and superconducting power transmission technology

The new transmission and distribution electric line technology is the basis for the development of power grids at all levels in China, and is an important way and a cornerstone for ensuring the reliability of power supply and achieving low-carbon power transmission. At present, the development of high-strength insulation technology still needs to solve core key technologies such as gas insulated pipeline technology and high-strength insulation materials for cables. The development of high strength insulation technology has significantly improved the performance of power transmission and transformation equipment, and has important practical significance for ensuring long-term safe and stable operation of the power grid.

Superconducting power transmission is the use of a superconductor in a superconducting state to have a high-density unimpeded current carrying capacity to realize large-capacity power transmission. The development of superconducting power transmission technology has been in the critical stage of transition from experimental demonstration to practical engineering application, and further breakthroughs are still needed in cable performance, core technology and economy. The development and application of superconducting power transmission technology will likely subvert the traditional transmission line.

In terms of high-strength insulation technology, the overall goal of future development is to improve transmission capacity, increase insulation strength, reduce loss, and achieve environmental friendliness and intelligence. By mastering the key technologies of high-strength insulation materials and mastering the core preparation process, the localization of advanced materials insulation materials can be realized in the future. In terms of superconducting power transmission technology, the overall goal of future development is high capacity, high efficiency, high reliability, and good compatibility with conventional power systems. By 2035, superconducting materials are expected to achieve mature production technology and lower prices. Superconducting power transmission has the basis of economic competition with conventional technology/equipment, and can realize multiple functions and operating modes.

4.4. Operational stability analysis and control technology

With the rapid development of new energy and direct current transmission, the widespread application of power electronics technology, profound changes in grid operation characteristics and mechanisms, the development of safety and stability analysis and control technology will provide a solid foundation and core guarantee for the grid.

In terms of operational stability analysis, key technologies include: future power grid operation mechanism analysis technology, key technologies for large power grid simulation, key modeling techniques, and trend analysis of large-scale new energy grid-connected grid stability. In terms of operational stability control, key technologies include: future grid operation control, active and reactive power regulation technology, and large grid operation evaluation system construction technology.

In the future, new energy will gradually become the main power source, and the grid operation will be in a more complex and ever-changing scenario. The responsibility and pressure for comprehensive improvement of grid security and operational efficiency are enormous. Focusing on meeting the future morphological changes and operational requirements of the power grid, the development of a new generation of power system operational stability analysis and control methods will be more actively adapted to the development trend of larger-scale power response, faster multi-control and broad participation, and respond to the great challenges of traditional basic theory. In the direction of grid
interconnection and large grid security and stability, it will realize the automatic response of complex working conditions dispatching, research and develop high-precision simulation technology, develop safe and stable control means to adapt to the self-decision control and protection behavior of complex scenes, and develop networked and perceptual transmission and transformation equipment to ensure the safe, reliable and efficient operation of China's power grid in the future.

4.5. **Energy Internet and a new generation of artificial intelligence technology**

Energy Internet is one of the important supporting technologies to realize the intelligent interaction and open sharing of the new generation of power system. The development of energy Internet in China is still in its infancy, and it still does not have the conditions for large-scale commercial operation. Besides the high construction cost and the lack of supporting energy price policies, the low overall technical maturity is an important restrictive factor.

The application of artificial intelligence to power systems in China include expert system and artificial neural network, which are mainly applied to power grid security, stability and operation, power asset management and intelligent operation and maintenance. But overall, it is still in the research and exploration stage, and there are few successful engineering applications.

In the energy Internet, the deep integration of energy and information is the overall goal of technology development. It is expected that the commercial operation of the energy Internet will be initially realized in 2035. In the new generation of artificial intelligence, artificial intelligence will gradually become a powerful measure to solve complex power grid problems and an effective tool to promote the evolution of power systems.

In response to the above gaps and shortcomings, in order to fully support the role of energy Internet in the new generation of power system, it is necessary to strengthen and improve the multi-energy coordination and control, information physical integration, information opening and sharing, marketization level of energy internet, and it needs to carry out technical research on multi-energy complementarity, energy information integration analysis, market mechanism and so on. In the new generation of electric power artificial intelligence, the following technologies need to be studied in depth: smart sensor technology, artificial intelligence platform technology, cutting-edge machine learning technology and intelligent robot technology.

All in all, the energy transformation requires comprehensive improvement of the various technical levels required for the development of the power grid, thereby improving the new energy access capability and safe and stable operation level of the power grid, vigorously promoting the efficient and flexible allocation of resources, and establishing intelligent, interactive and diversified energy supply service system.
5. Conclusion
China's energy structure has long been based on fossil energy, especially coal. The pressure of eco-environmental protection and pollution reduction is prominent. It is imperative to vigorously promote energy transformation and optimize energy structure. At present, China's energy and power system is in a critical period of upgrading and transformation, and new energy power generation will occupy an increasingly important position in the energy field. In the future, new energy will be connected to the power grid on a large scale, which will bring many challenges to the safe, stable and efficient operation of the power grid. Therefore, it is necessary to cultivate corresponding technologies to support the future development of the power grid. In the five key technical fields, efficient, low-cost, long-life energy storage technology focuses on enhancing the flexibility of the power grid; high reliability and low loss power electronics technology can significantly improve and realize the controllability of the transmission, transmission, distribution and use of power systems; high strength insulation technology and superconducting power transmission technology play an important role in ensuring reliable low-carbon, high-capacity transmission of power supply; the operational stability analysis and control technology is mainly used to comprehensively improve the safety and operational efficiency of the power grid; the energy Internet and the new generation of artificial intelligence technology can realize the deep integration of energy and information, which is the key to the future development of the power grid. The five technologies will comprehensively improve the energy transformation capability, resource allocation capability and intelligent interaction capability of the power system.

Acknowledgments
The paper is supported by the Science and Technology Program of State Grid Corporation of China (Research on Quantitative Analysis and Development Model of Multi-dimensional Path Evolution of Power Grid for Future Energy Development SGHB0000KXJS1800415).

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