Study on the flexibility enhancement of China's power system with renewable energy

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Abstract. At present, China's renewable energy utilization scale has ranked first in the world. By the end of 2019, China's cumulative installed capacity of solar power had reached 204.3 million kW, and that of wind power had reached 210 million kW. Some parts of China already have a high proportion of renewable energy power systems. However, the lack of flexibility in China's power system has become a constraint to the development of renewable energy. This paper analyzes the current situation of the flexibility of China's power system and the problems facing the development of high proportion of renewable energy. It is proposed that the flexibility of China's power system should be improved by retrofitting the existing coal power system, controlling the scale of newly installed coal power plant, establishing the demand side resource utilization system, planning the energy storage application of the power system, and implementing the reform of the power market.

1. Introduction
With comprehensive progress of energy transformation revolution in all countries around the world, renewable energy represented by wind power and photovoltaic energy is developing rapidly. The high permeability renewable energy integrated power system has become an important development trend of the future power system. The International Energy Agency (IEA) predicts that 80 percent of the increase in global electricity demand over the next 10 years will be covered by renewables.

At present, China's renewable energy development and utilization scale ranks first in the world. According to the statistics of the China Energy Administration, China's installed capacity of wind and solar power has grown rapidly from 2010 to 2019, as shown in Figure 1. According to the statistics of China Electricity Council, China's total power generation reached 7.3 trillion kWh, of which renewable energy power generation (including hydropower, wind power, solar power and biomass power) was 2.0 trillion kWh in 2019. Renewable energy power generation accounted for 27.9 percent of total power generation, as shown in Figure 2. According to the commitment made to the world in 2020, China will strive to reach the peak of carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. By 2030, the total installed capacity of wind power and solar power will reach more than 1.2 billion kW. Based on this, it is estimated that from 2021 to 2030, China's new installed capacity of wind power and solar power will be no less than 72 million kW each year.

Due to the randomness and intermittency of renewable energy, when renewable energy is connected into the power system on a large scale, the fluctuation of net load of the system will be increased, which seriously affects the safe and stable operation of the system. According to the research results, the effective utilization of flexible resources to optimize scheduling can improve the reliability of the system. Therefore, improving the flexibility of the power system has become one of
the crucial problems to be solved when integrating high permeability renewable energy into the power system.

At present, China's power system, which is dominated by coal power, lacks sufficient strain capacity and is difficult to adapt to the high proportion of renewable energy in the future. Therefore, the goal of high proportion of renewable energy generation faces severe challenges. For China's current power grid structure, the flexibility of the power system determines the development space of renewable energy and determines the success or failure of China's power industry transformation.

Based on the analysis of the current situation of the flexibility of China's power system and the problems existing in the connection of renewable energy generation to the grid, this paper puts forward some suggestions to improve the flexibility of China's power system.

Figure 1. China's accumulated installation capacity of wind and solar power from 2010 to 2019.

Figure 2. Proportion of China's electricity generation from different types of energy in 2019.
2. The concept of power system flexibility

Power system flexibility can be viewed as the ability of a power system to respond to expected and unexpected changes in generation, load, and network disturbances. The flexibility of power system involves the planning, operation and control of power system, and the time span can be from seconds, minutes and hours to days, months and years. From the spatial scale of power grid, it can be divided into local, regional and whole network. Flexibility resources include peak regulation resources, frequency modulation resources, energy storage, demand side response, power grid flexible control, etc.

According to IEA, the flexibility of a power system represents its ability to maintain reliability by adjusting generation or load in the face of considerable disturbances, that is, the ability to respond quickly to both foreseeable and unforeseen events. The North American Electric Reliability Council (NERC) considers power system flexibility to be the ability of system resources to meet changes in demand.

3. Current situation of power system flexibility in China

China's installed power generation is mainly coal-fired power generation, with less than 6 percent of pumped storage and gas-fired power generation.

North China, northwest china and northeast china are abundant in renewable energy. By the end of 2019, the installed capacity of wind power and solar power in these regions account for 70 percent and 56 percent of the total installed capacity of wind power and solar power in China respectively. However, flexible adjustment power supply in this area is less than 3 percent. In winter, due to the large ratio of heating units, the peak regulation capacity is very limited. Influenced by design, coal power price mechanism and other factors, the maximum peak adjustment range of coal-fired units in China is generally set at 50 percent. The minimum load and slope climbing rate of conventional units have fallen behind the actual technical level of units, and further lag behind the level of leading countries such as Denmark and Germany. Among the main flexible power sources in China, the development scale of pumped storage power stations and gas power stations is relatively limited due to resource constraints. In addition, energy storage technology at the present stage is limited by economy and safety, and cannot be commercialized on a large scale. Therefore, the flexible transformation of coal-fired generating units has become an effective way to promote the development of clean energy in China. However, during the period 2016-2020, the progress of the flexibility transformation of coal-fired generating units is very slow, mainly because the current compensation price for auxiliary peak shaving services is low, which cannot generate transformation incentives.

In 2020, Qinghai Province will become the first province in China with 50 percent renewable energy installed capacity. In the future, the high proportion of renewable energy power system will be expanded from local areas to the whole country, and the proportion will further increase. It can be found from the data released by China Energy Administration, due to the inflexibility of the power system, China has experienced severe wind and solar power curtailments in the past few years, as shown in Figure 3.
Figure 3. Curtailment rate of wind and solar power in China from 2011 to 2019.

4. Problems caused by high proportion of renewable energy power generation

4.1. The operational risks of the power grid have increased dramatically
Renewable energy power generation has weak support and low disturbance immunity. With the large-scale access of renewable energy, conventional power supply has been replaced greatly, the frequency and voltage regulation capacity of the power system continues to decrease, and the risk of large-scale, broadband and chain failures of the power grid continues to accumulate. When system accidents occur, such as large-scale unit failure, large-capacity line trip, DC commutation failure or locking, etc., renewable energy units are prone to large-scale off-grid, leading to chain failures. This problem is becoming increasingly prominent with the rapid growth of renewable energy. In addition, the access of a large number of distributed renewable energy sources to the grid may cause problems such as system power imbalance, line overload and node voltage overrun, which will bring significant challenges to the reliability of power supply.

4.2. Renewable energy power generation is difficult to control accurately
The total amount of renewable energy power generation units far exceeds conventional hydropower and thermal power units. In 2020, there were more than 4,000 large-scale renewable energy stations and 1.7 million distributed power generation units in the areas operated by the State Grid. In the future, the number of renewable energy power generating units in China may reach tens of millions, and signals such as meteorological environment and operational control may reach billions. System scheduling and operation are extremely complex, and control configuration measures and implementation are difficult. Renewable energy power generation equipment operating state perception ability is weak, operation management is extremely complex, the existing information means cannot fully meet the renewable energy power prediction and control, controllable load and renewable energy interaction and other needs.

4.3. China's electricity market is not suitable for high proportion of renewable energy generation
The large-scale consumption of wind power and photovoltaic power generation requires thermal power, hydropower and other conventional units to provide a lot of auxiliary services such as peak regulation, voltage regulation and standby, but China's power market has not yet established a reasonable profit adjustment mechanism. China's power grid dispatching agencies mainly make power operation plans in the cycle of year, month, week and day, and the potential of optimizing day-ahead, day-day and real-time dispatching operation has not been fully explored. The large-scale integration of
wind power and photovoltaic power generation has greatly increased the frequency and workload of intra-day scheduling plan adjustment, which requires optimization of scheduling operation.

5. Key measures to improve the flexibility of China's power system

In order to achieve the coordinated development of flexible resources with renewable energy and traditional power sources, the following measures can be taken.

5.1. Controlling the scale of coal-fired power generation

China's current coal-fired power system is not flexible enough. However, the installed capacity of renewable energy is increasing year by year, showing a serious mismatch between the two. From the perspective of economy and technology, the flexibility transformation of coal power system at present stage can obviously improve the flexibility of power system. In view of the current situation that thermal power enterprises lack of transformation power, the government departments should establish and improve the peak regulation auxiliary service market and incentive mechanism. The government departments can ease the reconstruction cost through financial subsidies, tax incentives and other policies and measures, and give compensation to the flexible reconstruction units, so as to improve the expectation of profitability stability of the enterprises.

However, in the long run, the cost of flexible transformation of coal power generation will gradually increase. Therefore, relying on a large increase in coal-fired power capacity to support the development of a high proportion of renewable energy is not desirable. Compared with coal power units, gas-fired power units are the best peak-regulating power with high power supply efficiency, short start-stop time and fast climbing rate. With the decline of construction costs in the future, gas-fired power generation will provide a strong support for the flexibility of the power system.

5.2. Establish a market-oriented, professional and intelligent demand side resource utilization system

Power demand side management (DSM) is another important source of power system flexibility. By taking various measures to guide users to optimize the approach of electricity consumption, the fluctuation of electricity load can be subdued and the peaking and valley difference of load can be reduced. In addition, this measure can meet the flexibility requirements of the system by mobilizing the response resources of the load side, ensure the safe and reliable operation of the system, and promote the utilization of more renewable energy. Power demand side management mainly adjusts power load through incentive and price adjustment. Both of these two types of DSM can deal with the imbalance of power system from the demand side.

Incentive demand-side management is targeted at specific production processes and living habits. This mode manages and restricts its power consumption mode through administrative means, and encourages the adoption of advanced power-saving technology and equipment to improve the terminal power consumption efficiency or change the power consumption mode.

The mode of demand-side management through electricity price is mainly based on load characteristics, and the price lever is used to adjust the power supply and demand relationship. The change of electricity price can guide the users to change their consumption behavior and electricity consumption, so as to reduce the electricity demand and consumption.

China's power system can combine the construction of the Internet of Things and integrated energy services to accelerate the deployment of user-side information exchange equipment at key links. Through the mining, development, aggregation and transaction of user-side resources, the automation and intelligent invocation of demand-side resources are gradually implemented. Then according to the characteristics of demand-side resources, the classification and transformation of demand-side resources are carried out. A precise incentive mechanism adapted to users' wishes will be formed to achieve two-way interaction.

5.3. Explore ways for renewable energy to participate in power system regulation

The peak electricity of renewable energy has a low probability and short duration, and it needs to pay
a lot of extra cost to fully utilize it, thus reducing the overall economy of the system. After comprehensively considering the characteristics of different systems and the marginal costs and benefits of renewable energy utilization, operation and maintenance personnel can build a renewable energy utilization control system with the goal of minimizing the total cost of the overall power supply.

5.4. Make overall planning for energy storage applications in power systems
Energy storage systems of different technology types can help solve the problem of the balance between renewable energy power supply and user demand in the corresponding application scenarios. For example, pumped storage mainly solves the problem of system peak regulation and balance within a large time scale and a large regional scope, which is suitable for the development of centralized renewable energy. For another example, battery energy storage is more suitable for the development of distributed renewable energy because it can solve the problem of power balance in small time scale and local area. Pumped storage and electrochemical energy storage are not completely substitutes for each other. Reasonable determination of their development scale, facility layout, access scope and construction schedule can more effectively promote the development of renewable energy power in China.

5.5. Applying market approach to support renewable energy development
Upgrading China's existing provincial-level power market to a unified national power market could promote the development and utilization of clean energy in a wider area. Constructing a nationwide unified electricity market is one of the ways to maximize the benefit of market allocation of resources. Resource allocation through the market mechanism can effectively solve the problem of balance of interests between clean energy and conventional power supply and between different regions. It can also increase effective supply, balance supply and demand, and give full play to the initiative of each participant in the market.

China needs to create more responsive, real-time power markets that reduce trading timescales to the minute level, allowing the market to make timely price judgments. At the same time, China's power market also needs to establish a fair flexibility compensation mechanism, considering the characteristics of fast climbing ability and response accuracy, to price the flexibility resources appropriately, and realize the survival of the fittest of the flexibility resources. In the future power system operation, China's power system will be able to take load demand-side management, reserve capacity sharing, inter-provincial mutual aid and other means to reduce peak load shifting. In addition, the power system will also use the price mechanism to guide the demand side of the electricity, cutting peak consumption, thus reducing the new coal power generation installed and the construction of the supporting grid.

6. Conclusion
The overall flexibility of China's current power system is insufficient, which is difficult to sustain the development of high proportion of renewable energy. Efforts should be made on the power side, the user side and the market mechanism to improve the flexibility of the power system.

On the power side, in terms of comprehensive regulation ability and economy, the flexibility transformation of coal power is a feasible measure to improve the flexibility of the power system at this stage. However, for the forthcoming medium and long term power system flexibility needs, it is necessary to focus on the development of gas power, energy storage, demand response and other flexible resources.

On the user side, advanced technology and equipment can be implemented and the load characteristics of the power demand side can be guided through the price of electricity, so as to achieve better flexible regulation effect.

China's existing power market mechanism limits the flexibility of the system. Improving China's power spot market and ancillary service market is essential to enhance the flexibility of the power system. In the case of high penetration rate of renewable energy in the future, various flexible
resources such as gas and electricity, energy storage and demand response need to be stimulated through the price mechanism of the electricity market to adjust output according to load changes. Meanwhile, flexible regulation products should be introduced into the auxiliary service market.

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