Application of Flexible DC Transmission Technology in Power Grid under Large-scale Development of New Energy

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Abstract. Based on the analysis of the current situation of new energy development and the prominent problem of power abandonment in China, this paper discusses the application of flexible direct current transmission technology in power grid under the large-scale development of new energy in order to give full play to the advantages of optimal allocation of resources in power grid, improve the balance ability of power grid, expand the scope of new energy absorption, and fully analyze the advantages and disadvantages of flexible direct current transmission technology.

1. Current Situation of New Energy
In recent years, China's new energy has been developing rapidly. By the end of 2018, China's installed capacity of wind power was 183.94 million kilowatts, an increase of 7% year on year, accounting for 9.0% of the total installed power supply. The installed capacity of wind power is 12.45 million kilowatts, accounting for about 30% of the new installed capacity of wind power in the world.

After years of exploration and start, China's solar power generation has entered a period of rapid development since 2013, and its scale continues to expand. By the end of 2018, the installed capacity of solar power in China was 1738.81 MW, an increase of 33% year on year, accounting for 5% of the total installed power supply.
2. Characteristics of Power Grid under Large-scale Development of New Energy

Due to the inherent characteristics of random and intermittence of new energy output, large-scale new energy development, outward delivery and absorption put forward higher requirements for the convergence and transmission capacity, peak shaving and frequency modulation capacity and transfer support capacity of the power grid. The main reasons for the high abandonment rate in the power grid under the large-scale development of new energy are as follows:

1) Low proportion of flexible power supply and limited system regulation capability
The regulation capability of power system is mainly determined by the regulation performance of power supply, which is related to the power supply structure. The peak shaving depth of different types of power supply varies greatly. Nuclear power units are usually operated as a base load and less involved in system regulation. Condensate coal-fired units and heat-supply thermal power units have poor regulation performance. Gas, pumped storage, hydropower and other power sources can start and stop quickly, adjust greatly, and participate in the balance flexibly. Thermal power is the main power supply structure in China. The overall regulation performance of power supply mainly depends on the depth of peak shaving and flexible regulation of power supply proportion.

At present, thermal power still accounts for the largest proportion of installed power in our country, thermal power accounts for 70% of the total installed power supply, pumping, conventional hydropower and other flexible regulated power supply accounts for less than 8%, only 20% to 50% of installed new energy. In the United States and Spain, flexible regulated power sources (hydropower, fuel and gas, pumping) are 8.5 and 1.5 times higher than new energy sources. At the same time, more than 50% of the installed thermal power units in the large-scale development areas of new energy are cogeneration units. During the heating period, the regulation performance decreases dramatically, and the proportion of self-owned power plants in some areas is high, and they do not participate in peak shaving of power grid, which seriously affects the peak shaving ability of the system.

2) The development of new energy is concentrated in some areas, and the market of regional absorption is limited.

By the end of 2018, 70% of the installed scale of wind power and photovoltaic power in China was concentrated in the "Three North" area, but the proportion of electricity consumption in the "Three North" area was only more than one third of the country's total, and the market space for new energy consumption was limited.

The proportion of wind power installed in Gansu, Xinjiang and Ningxia has reached 96%, 77% and 74% of the maximum load, while the proportion of solar power installed in Qinghai and Gansu has reached 67% and 47% of the maximum load. New energy installed in Gansu, Ningxia and Xinjiang all exceeded the maximum load, with Gansu reaching a maximum of 1.4 times, and the development scale far exceeded the local absorption capacity.

3) The speed of new energy development is too fast and the capacity of cross-regional transmission channels is insufficient.

Most of the new energy in Northwest China is concentrated in remote areas far from the load center. It needs to be trans-regional transported to the load center areas in the middle and east of China for absorption, so as to expand the scope of new energy absorption.

Due to the short period of approval and construction of new energy station and the long period of approval and construction of new energy matching delivery project, the construction progress of planned new energy matching delivery project is obviously lagging behind that of new energy construction. At present, the trans-regional transmission capacity is less than 20% of the installed capacity of new energy, while the transmission capacity of foreign transmission channels can be as high as 1.1 times of the installed capacity of wind power.

3. Flexible DC Transmission Technology

Flexible HVDC technology has gradually matured, especially in Europe and the United States, dozens of flexible HVDC projects with different technical routes have been built, and a lot of engineering experience has been accumulated. In China, the technology has been in the stage of theoretical research for many years, and a large number of demonstration projects have just begun in recent years. In addition to the experimental Nanhui Project, the newly-built Zhoushan Project and Xiamen Project have been put into operation recently. At present, the State Grid Corporation is carrying out the design of Zhangbei Renewable Energy Flexible DC Power Grid Demonstration Project. The project has a voltage level of <500 kilovolts and a transmission capacity of 3 million kilowatts. It is expected that the project will be completed and put into operation at the end of the 13th Five-Year Plan.
The mature flexible HVDC transmission technology can provide more technical choices for the development of interconnection in China's power grid. Comparing with the traditional HVDC technology based on thyristor devices, flexible HVDC has the following advantages:

1) There is no need to provide reactive power on AC side, and there is no commutation failure. Traditional HVDC converter stations need to absorb a large amount of reactive power, which accounts for 40%–60% of the DC power, and need a large number of reactive power compensation devices. At the same time, the traditional DC system needs strong voltage support capability, otherwise commutation failure is easy to occur. Flexible DC technology has no such problems. At the same time, the active and reactive power can be independently controlled to supply power to the passive network.

2) Flexible HVDC technology can operate in 4 quadrants and control active power independently. It not only does not need reactive power from AC side, but also can supply power to passive network. It can play the role of STATCOM when necessary, dynamically compensate the reactive power of AC bus and stabilize the voltage of AC bus. If capacity permits, it can even provide emergency support of active power and reactive power to the fault system to improve the stability of power angle. Traditional HVDC transmission can only operate in two quadrants and cannot control active power or reactive power separately.

3) The harmonic content is small, and the filter devices needed are few. Whether it is a 2-level topology using SPWM or a flexible HVDC transmission technology using the nearest level approximation (NLS) sub-module multi-level topology, its switching frequency is higher than that of the traditional HVDC, the harmonics generated are much smaller than that of the traditional HVDC, and the capacity of the filter device required is small, and even no filter is needed.

However, due to the limitations of the manufacturing level and topology of voltage source converters, flexible HVDC transmission technology has limitations in the following aspects.

1) Transport capacity is limited. At present, the transmission capacity of flexible HVDC project is generally not high. Compared with UHVDC transmission, it can achieve more than 8 million kilowatts of active power. At present, the maximum design of flexible HVDC transmission is 1 million kilowatts. The main reason for the limitation is that the junction temperature capacity of the voltage source converter is limited, and the current capacity of the single device is generally not high, and the normal operating current can only reach about 2000 amperes. On the other hand, due to the voltage limitation of the DC cable, the maximum voltage level of the XLPE extruded insulated DC cable is 320 KV, so the flexible DC is adopted. The pole line voltage of the converter station is also limited. If overhead lines are used, the voltage level can be improved, but the reliability is greatly reduced; if oil-paper insulated cables are used, the construction cost will be greatly increased, and the transmission distance will also be affected.

2) High cost per unit transport capacity. Comparing with mature conventional HVDC transmission projects, there are fewer manufacturers of the equipment needed for flexible HVDC transmission projects. The main equipment suppliers, especially sub-module capacitors and DC cables, are limited in the world. They even need to arrange production according to the customization of the project, so the cost is high. At present, IGBT devices have a certain domestic production capacity, but the internal silicon wafers still rely mainly on imports. From the current construction cost of flexible DC projects in Zhoushan and Xiamen, the unit capacity cost is about 4-5 times that of conventional DC transmission projects. If flexible HVDC transmission is to reach the transmission capacity of UHVDC transmission, its cost is very considerable.

3) The fault tolerance and reliability are low. Because there is no DC circuit breaker suitable for high current interruption, and flexible HVDC cannot completely block fault current through IGBT devices from its topological structure, and it does not have the ability of DC side fault self-clearance, once DC side short circuit fault occurs, it is necessary to remove AC circuit breaker and block the whole DC system. The whole fault recovery cycle is longer than that of traditional DC. Flexible DC has low fault tolerance and reliability. If the bipolar symmetrical connection scheme is adopted, the reliability can be improved to a certain extent, but the recovery time of the fault pole will still be limited by the operation time of AC circuit breaker, and the speed of complete recovery of the whole system is not as fast as that
of traditional DC. This is also the main reason why the application of overhead lines in flexible HVDC transmission is limited.

4) Great loss. Whether it is a 2-level topology using SPWM or a flexible HVDC transmission technology using the nearest level approximation to NLS sub-module multi-level topology, its switching frequency is higher than that of traditional HVDC, and its switching loss is considerable. In the early stage of 2-level flexible DC project, the loss of converter station can reach 3%~5%. At present, the flexible DC project with multi-level sub-modules mostly controls the loss within 1%, which is equivalent to the loss of traditional DC, but the transmission capacity is still very small compared with traditional DC. If the capacity is increased, larger sub-modules and faster switching frequency will be needed, so the loss will also occur. Corresponding improvements.

5) The transmission distance is short. Because the overhead transmission problem is not well solved, the voltage of flexible HVDC transmission project is generally not high. At the same time, the relative loss of flexible HVDC system is large, which limits its effective transmission distance. The transmission distance of flexible HVDC project is mostly from tens to hundreds of kilometers. From this point of view, flexible HVDC transmission is not suitable for long-distance transmission.

At present, flexible DC technology is widely used in offshore wind power grid connection. Due to the limitations of technology and parameter level of voltage source converter and slow recovery after line failure, flexible HVDC still has some limitations, such as high control system requirements, small transmission capacity, high unit transmission capacity cost, high loss, high cost, short transmission distance, low fault tolerance and reliability. From the current development level of flexible DC technology, if flexible DC wants to greatly improve the transmission capacity and distance, it must break through the technical barriers such as voltage source converter, high current DC circuit breaker and so on. Therefore, flexible direct transmission technology will not be able to be applied to high voltage, large capacity and long distance power transmission on a large scale during the 13th Five-Year Plan period. The next ten years will be a period of rapid development of China's flexible DC. In the long run, with a series of key technologies such as voltage source converter breakthroughs and practical conditions, it will provide more technical options for grid-connected and absorption of new energy in China.

4. Conclusion
In order to adapt to the large-scale interconnection of new energy, the development ideas and patterns of power grid must be adjusted accordingly. In the future, we must focus on the layout of clean energy development and realize the complementary and mutually beneficial operation of different regions, seasons, periods and types of power supply by means of new technologies, improve the regulation capacity of power grids, obtain the benefits of multi-energy regulation of wind, light and water, meet the large-scale development and utilization of clean energy, and finally form a grid with clear structure of transmission and reception terminals and coordinated development of AC and DC. Bureau, give full play to the advantages of optimal allocation of grid platform resources, improve the efficiency of energy resources utilization, to meet the large-scale development and utilization of new energy.

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