

The Development and Current Situation of Flexible DC Distribution Technology

Shengquan He^{1,2}

¹National Energy Internet Innovation Center(guangdong) Co.,Ltd., Zhuhai 519000, Guangdong, China

²Gree Electric Appliances, Inc. of Zhuhai, Zhuhai, Guangdong, China

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Abstract: Against the strategic background of the “dual carbon” goals, flexible DC distribution technology has become a core pillar of the new power system with its high-efficiency, flexible and controllable technical advantages. It can not only coordinate the relationship between distributed generation and the power grid, but also adapt to high-proportion new energy access and promote the low-carbon transformation of the power grid. This paper analyzes the advantages and core technologies of flexible DC distribution technology, expounds its development status, and prospects its development path from three aspects: R&D of power electronic equipment, optimization of flexible DC distribution protection schemes, and coordinated development, aiming to provide a reference for the stable development of the new power system.

Keywords: Flexible DC distribution; Technical advantages; Key technologies; Development status; Future prospects

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1. Introduction

With the annual growth of power demand and the rapid development of new energy and power electronic technologies, traditional AC distribution technology can hardly meet the transmission and distribution requirements of the new power system, nor ensure the safe and smooth operation of the power grid. Therefore, power departments, research institutes and universities are actively promoting the R&D of flexible DC distribution technology. On the one hand, it is necessary to continuously optimize the performance of flexible DC distribution equipment and accelerate the innovation of core technologies; on the other hand, it is necessary to continuously expand the application scenarios of flexible DC distribution, so as to improve the resilience of distribution networks, promote the application of new energy, and implement the “dual carbon” goals.

2. Advantages of flexible DC distribution technology

2.1. More advanced technology

Compared with AC distribution technology, flexible DC distribution technology features transmission lines with smaller land occupation, less material consumption and lower losses during power transmission^[1]. First, distributed generation can be directly connected to the flexible AC distribution system. Using the advantages of AC phase and frequency tracking, it can flexibly convert electric energy transmitted by distributed generation, making the distribution process more reliable. Second, flexible DC distribution technology reduces the conversion links in power transmission and distribution, which not only cuts transmission losses but also dynamically monitors the power transmission process, further improving the stability of power system operation. Third, the flexible DC grid has a more diversified architecture and supports various power supply topologies, facilitating power departments to design diversified transmission networks to meet the power needs of different users and promote the high-quality development of the power industry.

2.2. Wider application scope and higher economic value

In the new era, new energy electric vehicles, smart home appliances and other loads require DC drive, which virtually increases the grid load and puts forward higher requirements for the stability and transmission efficiency of the power system.

Flexible DC distribution technology can directly supply power to loads requiring DC drive, reducing conversion links in power supply, improving power transmission capacity, thereby lowering power loss and user electricity costs. It meets the power demand of large commercial centers, enterprises and other users, helping them save electricity expenses and laying a solid foundation for urban commercial and industrial development^[2].

3. Analysis of key technologies and equipment for flexible DC distribution

3.1. Key technologies

Topology is one of the core technologies of the flexible DC distribution system, which affects the performance of distribution protection devices and the smooth operation of the entire power system. At present, the topologies of flexible DC distribution technology mainly include the following two types.

- (1) The single-ended radial topology, which is simple and highly adaptable, is one of the most widely used topologies. It operates stably in low-voltage DC distribution networks and reduces power losses during transmission;
- (2) The double-ended radial topology transmits power through two AC systems and then supplies power to the DC bus via converters. It is widely used in power grids with concentrated power loads^[3].

3.2. Key equipment

With the gradual maturity of high-voltage DC technology, hardware equipment in the power grid system has become increasingly diversified, effectively improving power transmission and distribution efficiency. However, hardware equipment has also become a high-failure area in flexible DC distribution systems. This paper takes energy routers and DC transformers as examples to analyze the characteristics and functions of key equipment. First, the energy router is one of the core hardware devices of the flexible DC distribution system. It can not only flexibly switch the power flow direction of electric energy interfaces

but also realize the hybrid application of AC and DC power, effectively improving the flexibility and safety of the power system and maximizing the operating efficiency and power supply quality of the DC distribution system. In addition, the energy router is highly flexible, which can improve the adaptability of DC distribution technology, further expand the application scenarios of flexible DC distribution, and promote the development and popularization of DC distribution technology^[4]. Second, the DC transformer plays an important role in the flexible DC distribution system. Equipped with more sensitive and intelligent power electronic devices, it can directly complete DC-to-DC conversion and realize DC-to-AC voltage conversion through expansion modules. Meanwhile, the DC transformer supports bidirectional conversion and can directly boost or reduce DC voltage to meet the transmission needs of buses with different voltage levels, further improving the stability of the entire flexible DC distribution system.

4. Development status of flexible DC distribution technology

4.1. Development of flexible DC distribution technology abroad

The United States is one of the earliest countries to conduct research on DC distribution networks. Virginia Tech proposed the “Sustainable Building Initiative (SBI)” research program in 2007, aiming to build a hybrid distribution system to realize AC-DC conversion and provide high-quality power services for residences and office buildings^[5]. In 2010, the university put forward the “Sustainable Building and Nanogrids (SBN)” program, connecting DC 380V and DC 48V buses of two voltage levels into the power system to supply power to loads of different levels, gradually optimizing the DC distribution network.

Politecnico di Milano proposed the “DC distribution system architecture based on distributed generation” in 2004, designed the access mode of distributed generation to DC distribution networks, and put forward the conversion method of AC and DC power, further improving the stability of the power system^[6]. Since 2008, the UK, Switzerland and other countries have jointly carried out the “UNIFLEX (Universal and Flexible Power Management)” research, cooperating in the development of current conversion technology and hybrid grid design to improve the power capacity and transmission and distribution stability of the European power grid.

Tokyo Institute of Technology proposed the concept of “DC microgrid-based distribution system” in 2004 and developed a 10kW DC distribution system prototype. Osaka University put forward the concept of “bipolar structure DC microgrid system” in 2006, converting DC voltage through bidirectional rectifiers and distributing power through power electronic converters to meet various power supply demands^[7].

4.2. Development of flexible DC distribution technology in China

China’s research on flexible DC distribution technology started in the early 21st century. The initial research focused on the R&D of DC distribution hardware equipment and hybrid distribution network design, and then gradually focused on the engineering development of DC distribution technology with increasingly diversified application scenarios and more mature technologies. In 2010, Chinese researchers broke through the technical bottlenecks of power devices such as IGBTs and converter valves, independently developed power electronic devices and converter valve technologies, and built low-voltage/medium-voltage flexible DC distribution network pilots in China^[8].

In recent years, China has focused on the “PV-Storage-DC-Flexible” concept, exploring the application paths of flexible DC distribution technology in industrial parks, commercial centers, urban distribution

networks and rural power grids to promote the long-term development of China's new power system ^[9]. With the gradual improvement of the new power system, China has built a number of demonstration power projects and applied flexible DC distribution technology to new projects. For example, the Zhangbei Flexible DC Grid has realized large-scale new energy-friendly grid connection; the Tai'an Zero-Carbon Park and Yunnan PV-Storage-Charging Integration Project have verified the energy efficiency advantages of "PV-Storage-DC-Flexible", effectively improving the power supply reliability and safety of the new power system ^[10].

5. Future prospect of flexible DC distribution technology

5.1. Strengthen coordinated management of AC/DC power sources and loads

The biggest advantage of DC distribution technology is to improve the consumption capacity and power of distributed units, meet the operation needs of power supply networks for different power loads, thereby reducing intermediate conversion links and lowering power losses in transmission and distribution ^[11]. To further improve the stability of DC distribution technology, power departments should strengthen cooperation with research institutes and universities, actively optimize the design scheme of AC/DC distributed power supply equipment, and build an integrated control system. This will realize the coordinated management of AC/DC distributed power sources and load control systems, further improve the AC/DC voltage control effect, and better promote flexible DC distribution technology ^[12].

5.2. Actively develop intelligent power electronic equipment and control systems

With the accelerating intelligentization of the national power grid, artificial intelligence, Internet of Things (IoT), cloud computing and other technologies are more and more widely used in the power system, laying a solid foundation for the development of flexible DC distribution technology.

In this context, researchers should base on the characteristics of DC distribution technology and focus on core technologies such as converter topology, DC circuit breakers and energy management to develop intelligent power electronic equipment. Examples include more sensitive converters, DC transformers and DC circuit breakers with better heat dissipation and stability, to meet the operation needs of DC distribution networks ^[13].

Meanwhile, researchers should actively develop intelligent control systems for DC distribution. Through IoT and cloud computing, they can monitor the operation of each branch of the distribution network and the power load of each circuit in real time, intelligently evaluate power consumption, so as to rationally dispatch power resources and further improve the resilience of DC distribution.

5.3. Continuously improve DC distribution protection schemes

DC distribution technology can meet industrial, civil and commercial power demand. Different DC distribution topologies are adopted according to user needs, equipped with hardware equipment of different power and functions, and different transmission lines are designed ^[14].

Therefore, technicians should design protection configuration schemes according to the needs of DC distribution networks. On the one hand, it is necessary to evaluate the operation risks of DC distribution networks, find out faults that are prone to occur in the distribution process through virtual simulation technology, and formulate effective fault diagnosis and maintenance schemes. This ensures the smooth operation of the DC distribution network and reduces power outages, short circuits or transformer failures.

On the other hand, technicians should reasonably divide protection areas according to the characteristics

of the DC distribution system, adopt different protection configuration schemes for different areas, monitor power loads and dispatch power under the control of power electronic devices, timely detect and solve potential safety hazards during the operation of the DC distribution network, and ensure the smooth operation of the power supply system ^[15].

In the future, flexible DC distribution will become one of the mainstream technologies in power system development and gradually transform to modularization, intelligence and low cost to meet the needs of urban distribution and rural power supply. Power departments, research institutes and universities should deepen cooperation, actively integrate digital twin technology, artificial intelligence and virtual simulation technology into DC distribution network design, continuously improve DC distribution technology, promote the integrated development of “PV-Storage-DC-Flexible” in China, and provide technical support for the low-carbon transformation of China’s power system.

6. Conclusion

In short, flexible DC distribution technology has laid a solid foundation for the construction of smart grids in China, improved the new power system, and supported the improvement of power transmission and distribution technology levels. In the future, power departments should actively introduce intelligent equipment, promote the application of DC distribution technology in cross-regional power distribution and smart grid construction, give full play to the role of DC distribution technology in new energy consumption and flexible load regulation, reduce energy loss in transmission and distribution, accelerate the realization of the “dual carbon” goals, and promote the high-quality development of China’s power system.

Disclosure statement

The author declares no conflict of interest.

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