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中国智能输电系统发展现状分析及建议

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Analyses and Suggestions on Current Development Status of Smart Power Transmission Systems in China

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ABSTRACT: In view of the characteristics, such as highly compatible power access capability, high security and reliability, and great flexibility and controllability, the application of smart grids in power transmission systems will improve both operation security and stability of power grids in China. Based on the development conditions of the Three-Hua UHV synchronous power grid, which connects North China, Central China and East China Grids, the necessity of applying smart grids to large-scale interconnected power systems in China is analyzed, the current development status of smart grids in domestic power transmission systems is reviewed, and suggestions on the development of smart grids in China are provided.

KEY WORDS: power system; power transmission system; smart grid; current development status; suggestions on development

摘要：智能电网高度兼容的电力接入能力、安全可靠性、灵活可控性将极大提高我国电网的安全稳定运行水平。根据我国未来形成的“三华”特高压同步电网的现状，分析了我国大型互联电力系统发展智能电网的必要性，对我国输电系统智能电网发展现状进行了综述，提出了我国输电系统智能电网发展的建议。

关键词：电力系统；输电系统；智能电网；发展现状；发展建议

0 Introduction

Western, northern and south-western China areas, which are relatively under developed, own most of primary energy resources in China, while most of the produced energy are consumed by the developed areas in eastern coastal China. The specific condition is as follows: 77% of recoverable coal deposits are stored in western and northern areas, 65% water energy storage is stored in south-western areas, most of land wind energy resources are owned by north-eastern area, “Three North” areas and northern of north China. Two thirds of energy consumption requirements come from the middle and eastern developed areas. Due to this significant mismatch between energy resources supply areas and energy consumption areas, the energy transportation in China during the past long period has the following features: large scale, long distance and coal as the main goods.

Based on the intensive exploitation of large-sized coal power, water power, nuclear power and renewable energy bases, State Grid Corporation of China (SGCC) targets to accelerate the development of strong power grids with UHV backbone, and implement large-scale, long-distance and highly efficient electric power transportation. By fully using the large-sized grids as the carrier of energy resource allocation optimization, China targets to optimize the energy resource allocation in the whole country, and guarantee the stable energy supply for a long period.

With the increasing electrification level, power generation enterprises and power customers will have new and higher demands for improving service quality and service principles. In order to guarantee the power production and transmission, power generation enterprises need the power grids to provide reliable, efficient and flexible power access. Power customers will be able to flexibly choose power supply modes, and demand high quality and reliable power supply with low price from the power grid. The interaction between customers and the power grid is necessary to achieve the highly efficient and economic power utilization. Furthermore, customers could send the distributed electric power to the power grid in the appropriate time to realize clean and efficient energy utilization.

The Three-Hua UHV synchronous power grid will become the largest and the most complicated AC and DC hybrid grid in the world. This power grid spans wide regions, possesses multiple voltage levels, and has complicated and changeful operation modes and dynamic behaviors. Since the existing offline analysis methods are not suitable for Three-Hua UHV power grid any more, innovative analysis technologies have to be proposed. The several large-area power blackouts, which happened in US and European, have proven that there is always a long duration from the occurrence of the first failure to final system disintegration in large power grids. If the trends in power systems can be predicted and controlled by the dispatching and operation engineers, the system failure can be effectively stopped by prevention and control.

Based on the physical power grids, smart grid is a new type of grid, which integrates the physical grids with modern advanced sensor measurement, telecommunication, information, computer science and control techniques[1-2]. Among these, the most important include wide area measurement, flexible AC transmission system (FACTS), high voltage DC transmission, digital grid and digital substation. The targets of smart grid are as follows: to fully satisfy customers' requirements for electric power; to optimize resource allocation; to ensure the safety, reliability and economy of power supply; to meet environment protection constraints; to guarantee power quality; to adapt to power marketization development, etc. Smart grid can provide customers with the reliable, economic, clean and interactive power supply and other value-added services.

The operation safety and stability of Chinese power grids can be significantly improved by smart grids, which have highly compatible power access capability, high security and reliability, as well as great flexibility and controllability. Smart grids can satisfy future increasing requirements of power generation enterprises, power grids enterprises and power customers, and promote the healthy sustainable development of electric power industry.

1 Current development status of smart power transmission systems in China

1.1 Wide area measurement

Wide area measurement techniques are the basis to realize digitalization and informatization of power transmission grid. In recent years, the research and applications in this area have been developed quickly in China[3]. Till the end of 2008, the wide area measurement systems (WAMS) have been put into operation at all provinces except Qinghai and Jilin. According to the statistics, there are more than 1 000 sets of phasor measurement units (PMU) having been deployed in Chinese power grids. Now China can independently produce PMU devices, whose performance, accuracy and capability are in the international leading level.

Although started earlier, the WAMS research in other countries were stagnated on power grid real-time monitoring and failure analysis. Beginning from 2002, the synchronized phasor measurement in China has been advanced quickly. Currently, all functions of WAMS made by China reach the leading level in the world. In 2004 and 2005, two big disturbance experiments using WAMS[4] were completed in north-eastern grid. It was the first time in the world to implement experiment with big manual disturbances, and use PMU/WAMS to record and analyze. Besides power grid dynamic process monitoring and disturbance identification, Chinese researchers also try to implement system protection and control based on WAMS. From 2005, eastern China grid began to build wide area monitoring analysis protection-control (WAMAP) system[5]. At present, some functions, including the PMU-based online safety and stability quantitative analysis, online decision support for safety and stability prevention and control, and online pre-decision for safety and stability emergency control, of WAMAP have been verified through real time digital simulation experiments. In the near future, the WAMAP will be applied in the practical systems. In 2008, the WAMS and PMU had been applied in wide-area control by southern China grid, which had developed the PMU-based multi-DC coordinate control system, and had successfully completed close-loop big disturbance experiments. It was the first time in the world to finish this kind of experiments in the practical grid.

1.2 FACTS

FACTS is an important method to realize economic and safe power transmission grid. In the research and application areas of FACTS techniques[6], SGCC stands in the world's leading position. It has obtained plentiful achievements and successful application experiences in FACTS techniques, such as fixed series compensator (FSC), thyristor controlled series compensator (TCSC), static var compensator (SVC), controllable shunt reactor (CSR), static synchronous compensator (STATCOM), and also began the research work on fault current limiters

(FCL), static synchronous series compensator (SSSC), unified power flow controller (UPFC), etc.

1）FSC/TCSC. The research and application of serial compensation technique in China began in 1954; while the practical applications started from 2000. At the end of 2004, the first domestic hybrid FSC and TCSC project was successfully deployed in Chengxian substation. In July 2006, the first domestic set of 500 kV serial compensation devices was deployed in 500 kV Dongsan line III of Sanpu substation. In Oct. 2007, the TCSC devices with the greatest capacity and highest voltage in the world, which were independently developed by SGCC, were deployed in Yifeng 500 kV dual-circuit line. The sub-synchronous resonance problem was solved effectively by these TCSC devices, and the transmission capacity was increased by 1 000 MW, which is equivalent to the capacity of a new 500 kV transmission line. By the end of 2007, the deployed serial compensation capacity in China reached 4 213 Mvar, among which there are three TCSC projects with a total capacity of 849.8 Mvar. In the next several years, there will be more than 3 000 Mvar serial compensation capacity deployed annually. Currently, the key serial compensation technology for UHV is under research.

2）SVC. SVC application began from 1982 in China. From 1982 to 2004, 6 sets of SVC, all of which were imported from aboard, have been installed. The operation results of these SVC systems were not good, due to the old import time, the low level of automation, bad adaptability to Chinese grids and bad technical support, etc. In 2004, SGCC produced the first domestic set of SVC, which was successfully deployed in Anshan-Hongqipu No.1 substation, Liaoning. In 2006, 3 sets of SVC were successfully deployed in corridor of “power transmission from Sichuan to Eastern China”. The total capacity of these SVCs reaches 420 MW, which increases the transmission capability of Sichuan-Chongqing section by 214 MW, and introduces good damping effects on 1 Hz low frequency oscillation to the system.

3）CSR. The research and application of CSR in China started relatively late, but has been advancing quickly. In 2006, the 500 kV high resistance transformer type CSR, which was jointly developed by SGCC and Xi’an Transformer Factory, was successfully deployed in Xindu station. In 2007, the 500 kV magnetic controlled CSR, which was jointly developed by SGCC and Shenyang Transformer Works, was successfully deployed in Jiangling converter station. The 1 000 kV UHV CSR, which is under research and development, will be used in the pilot project.

4）STATCOM. The research on STATCOM in China began from 1986. In March 1999, SGCC and Tsinghua University jointly developed a GTO-based 20 Mvar STATCOM device, which was deployed in Chaoyang 220 kV substation, Luoyang, Henan province. In February 2006, SGCC and Tsinghua University jointly developed the world’s first IGCT-based 50 Mvar STATCOM device, which was successfully deployed in Xijiao substation, Huangdu distinct, Shanghai.

5）FCL. Through installing appropriate FCL at the proper location, the increase of interconnections and power supply capacity will not be limited by the short circuit current level any more, which is important to the safe, stable and economic operation of the whole system. Furthermore, FCL is important to the establishment and operation of Chinese future super-scale interconnected power grid. During the development of Chinese first set of 500 kV serial resonant FCL implemented by SGCC, the key technology breakthrough was realized. The pilot project was deployed at Pingyao power station, Zhejiang, in November 2009.

6）UPFC. UPFC is the 3rd generation FACTS device, which combines the functions of several FACTS devices, such as STATCOM and SSSC. UPFC can control the basic parameters of power transmission (voltage, resistance and phase angle) in real time. Under any combination of these three parameters, UPFC can optimize transmission power and system network flow distribution, realize accurate regulation of the active and reactive power, and fully utilize existing lines’ capacity. As the FACTS device with the best generality till now, UPFC is also able to damp system oscillation and improve system stability. Now the preliminary technique is under research.

Through the formulation of Framework of Key Power Electronics Technology Research for Power Systems, SGCC will continue the research on FACTS techniques, including 750 kV/1 000 kV FSC/TCSC, mobile SVC and its demonstration, 750 kV/1 000 kV CSR, 500 kV FCL and its demonstration, larger capacity STATCOM, etc. After the breakthrough of key issues in some areas, Chinese FACTS techniques will play an important role in the construction of smart grid.

1.3 High voltage DC transmission

High voltage DC transmission system has many advantages, including great transmission capacity, low transmission loss, flexible and fast flow adjustment, high level of automation and intelligence, etc[7]. It will be a key component of smart grid. Currently, SGCC is independently developing the high voltage DC converter valve, which had been applied in Lingbao DC extension project at the end of 2009.

The voltage source commutation DC transmission technology based on the new type of power electronics devices is a revolution in DC transmission field. This technology significantly extends the application fields of DC transmission technology, and improves the speed and flexibility of flow adjustment. It can be applied in power transmission, power distribution, and passive network, and can also be used to establish DC transmission and distribution networks. Combined with super conduction and energy storage, it will become the key basis of future smart grid with distributed power supply. After having completed the prophase research and basic theoretical research, SGCC is researching the key technologies of flexible DC and will build a pilot project.

1.4 Dispatch automation and digital power grid

Based on the independent research and development, SGCC has completed and is doing many research and applications on the following: digital grid, grid dispatch automation, power system's online stability analysis, power grid control, visualization and data integration, power dispatching data network, standardization of monitoring system, etc[8]. Many significant advances have been achieved in a lot of fields.

The existing State Grid Dispatching Digital Network (SGDDN) is a private data network which directly serves for power dispatching control. SGDDN is a data transmission and exchange platform among dispatching institutions, and between dispatching institutions and power stations. SGDDN has become an indispensable basic facility, since it provides high quality private data transmission service for power grid production and control system. With the world-leading dispatching data network, China can provide reliable network data transmission platform to smart grid.

The following independently developed systems have been widely applied in the dispatching institutions above province level: energy management system (EMS), WAMS, protection and fault information management system, dispatcher training simulator (DTS), waterpower scheduling automation system, electric energy measurement system, integrated data platform, electric power trade management system, dispatching management system, etc. Grid's online safety and stability early warning and decision support functions have been initially implemented in National Electric Power Dispatching and Communication Center and some regional and province level grids. The technologies used in independently developed power grid dispatching automation systems OPEN-3000 and CC-2000A reached the international advanced level. Compared with the foreign systems, Chinese systems have obvious advantages in automatic voltage control, relay protection and security control device, online stability analysis and early warning, dynamic stability control, etc. But they should be improved in the field of power market application.

The establishment of UHV power grid, the development of national power grids and pilot of energy-saving power generation and dispatching raise new requirements for power grid dispatching and operation, optimal allocation of resources, and coordinated control. Currently, SGCC is developing the wide area panoramic, distributed and unified power grid dispatching technology support system, which is no more a loose system consisting of single functions from EMS, WAMS, etc. This system is tightly coupled with the practical requirements from safe and stable operation of large grid, energy-saving power generation and dispatching, dispatching management and redundant dispatching. In addition, it will research and develop the following powerful intelligent application functions: power grid real-time monitor and control, analysis and early warning and decision support, dispatching plan for safe and economic coordination and optimization of energy saving, integration of information from different time sequences and spaces, etc. Besides improving the safe and stable control level and safe and economic operation level of huge-scale power grids, this system can also improve the management and decision level of power grids, and provide technology basis for future establishment of smart grid.

1.5 Digital substation

The digital substation is the important intelligent node in a digital power grid. From the end of the 1990s, the research on IEC61850 began in China[9]. In current phase, the digital substation has three features: application of digital instrument-transformer and intelligent high voltage devices, IEC61850 based standard information model and information processing via network, and intelligent operation management. Based on these features, it is possible to build an automated substation which is integrated with measurement, control, protection and information management. In the field of digital substation, SGCC has obtained some achievements, which meet the requirements of smart grid in the aspects of primary devices and communication networks of substation. Currently, there have been more than 300 digital substations deployed in China.

2 Suggestions on development of smart power transmission grid

2.1 Develop smart power transmission grid in high priority

The power industry in US and Europe is already in the mature phase, in which the establishment of power grids tends to be stable, the electric power demands tend to be saturated, the power supply and redundant storage tend to be balanced, and the change of transmission grid architecture is small. In order to improve safety of power grid and maximize market benefits, current research and application of smart grid focus on power distribution and consumption in US and Europe.

The rapid economic development trend in China will be kept for a long time. The features of power grid in China include the rapidly increasing load, fast developing power systems, and rapidly changing network architectures. Chinese power grids will achieve optimal allocation of energy resources in a larger scope, by establishing UHV grids, and intensively exploiting the large-sized coal power, water power, nuclear power and renewable energy bases. Thus, the establishment of Chinese smart grid should have Chinese characteristics. Currently, the smart transmission network should be developed in high priority. At the same time, smart distribution network should also be considered, to ensure safe and stable operation of large-scale power grid and provide access to renewable energy, therefore dealing with the future challenges in power industry.

2.2 Consider the plan, design and establishment of power grid as a whole

In UHV transmission system, during the establishment of power grids and import of information and control, the overall process of plan, establishment, reform and upgrade of power grid should be considered. The intelligent operation control and maintenance should be achieved in the whole power grid. Furthermore, the objectives of being more safe, reliable, economic and environment-friendly should be carried out.

2.3 Implement theory and technology innovation and application for smart grid

Theory and technology innovation and application are the only way to implement smart grid. New transmission technologies (such as FACTS, VSC-HVDC, superconducting transmission, etc.) should be developed to improve flexibility and economy of system operation. The power energy storage technology should be developed to solve intermittent supply of renewable energy. The parameters measuring technology should be developed to monitor device health status and network status, to support relay protection and measure power energy. The power grid stable operation theory, online monitoring, and new early warning technologies, should be developed to provide scientific basis for smart grid analysis. The decision making support technologies should be developed to enhance decision capability of operation engineers at all levels.

2.4 Establish uniform specification and standard architecture for smart grid

As the key link in building Chinese smart grid, the establishment of uniform specification and standard architecture is also the basic guarantee for normal operation of smart grid. All parties' research forces should be concentrated under the uniform management of SGCC. The existing power industry standards and communication standards should be integrated with the power system architecture to form complete specifications and standards architecture based on smart grid. The ultimate objective is to achieve information integration and sharing among all links from power generation to consumption.

3 Conclusion

With the capabilities of being digital, information-based, automatic and interactive, smart grid can provide technical guarantee for safe and stable operation of large capacity and long distance power transmission in China. In this paper, the current development status of smart power transmission systems in China is analyzed. And the following suggestions are proposed on the development of smart grid: 1）develop smart power transmission grid in high priority; 2） consider the plan, design and establishment of power grid as a whole; 3）implement theory and technology innovation and application for smart grid; 4）establish uniform specification and standard architecture for smart grid.

References

[1] DOE．The smart grid: An introduction[EB/OL]．2008-09-10 [2009-04-20]．http://www.oe.energy.gov/DocumentsandMedia/DOE_SG_Book_Single_Pages(1).pdf．

[2] European SmartGrids Technology Platform．Vision and strategy for Europe's electricity networks of the future[EB/OL]．http://www.smartgrids.eu/documents/vision.pdf．

[3] 常乃超，兰洲，甘德强，等．广域测量系统在电力系统分析及控制中的应用综述[J]．电网技术，2005，29(10)：46-52．
Chang Naichao，Lan Zhou，Gan Deqiang，et al．A survey on applications of wide-area measurement system in power system analysis and control[J]．Power System Technology，2005，29(10)：46-52(in Chinese)．

[4] 徐兴伟，陶家琪，高德宾，等．实时动态监测系统在东北电网负荷建模中的作用[J]．电网技术，2007，31(5)：45-49．
Xu Xingwei，Tao Jiaqi，Gao Debin，et al．Application of wide area measurement system to load modeling in Northeast Power Grid[J]．Power System Technology，2007，31(5)：45-49(in Chinese)．

[5] 曹路，汪德星，岑宗浩．广域测量系统在华东电网中的应用[J]．电力设备，2005，6(12)：38-41．
Cao Lu，Wang Dexing，Cen Zonghao．Application of WAMS in East China Power Grid[J]．Electrical Equipment，2005，6(12)：38-41(in Chinese)．

[6] 王树文，纪延超，马文川．灵活交流输电技术[J]．电力系统及其自动化学报，2007，19(3)：113-117．
Wang Shuwen，Ji Yanchao，Ma Wenchuan．Survey of flexible AC transmission system technology [J]．Proceedings of the CSU-EPSA，2007，19(3)：113-117(in Chinese)．

[7] 袁清云．我国特高压直流输电发展规划与研究成果[J]．电力设备，2007，8(3)：1-4．
Yuan Qingyun．Development planning and research accomplishments of UHVDC power transmission in China[J]．Electrical Equipment，2007，8(3)：1-4(in Chinese)．

[8] 蒋荣安，阎平．三维数字化电网技术辅助特高压工程施工管理[J]．电力勘测设计，2007(5)：65-68．
Jiang Rong'an，Yan Ping．Application of 3D digital electricity network technique in the construction management of extra high voltage engineering[J]．Electric Power Survey & Design，2007(5)：65-68(in Chinese)．

[9] 高翔．数字化变电站应用展望[J]．华东电力，2006，34(8)：47-53．
Gao Xiang．Application prospects of digital substations[J]．East China Electric Power，2006，34(8)：47-53(in Chinese)．

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