A Review on Development Practice of Smart Grid Technology in China

HAN Liu[1],Chen Wei[1],ZHUANG Bo[2] and SHEN Hongming[1]

[1]State Power Economic Research Institute, Beijing 102209, China; 2. State Grid Jibei Electric Company Limited, Beijing 100051, China

Email: hlhanliu@163.com

Abstract: Smart grid has become an inexorable trend of energy and economy development worldwide. Since the development of smart grid was put forward in China in 2009, we have obtained abundant research results and practical experiences as well as extensive attention from international community in this field. This paper reviews the key technologies and demonstration projects on new energy connection forecasts; energy storage; smart substations; disaster prevention and reduction for power transmission lines; flexible DC transmission; distribution automation; distributed generation access and micro grid; smart power consumption; the comprehensive demonstration of power distribution and utilization; smart power dispatching and control systems; and the communication networks and information platforms of China, systematically, on the basis of 5 fields, i.e., renewable energy integration, smart power transmission and transformation, smart power distribution and consumption, smart power dispatching and control systems and information and communication platforms. Meanwhile, it also analyzes and compares with the developmental level of similar technologies abroad, providing an outlook on the future development trends of various technologies.

1. Introduction

Smart grid is defined as one kind of new power grid that combines multi technologies such as highly integrates information technology, communication technology, computer technology, advanced power electronic technology, renewable energy power generation technology and with original power transmission and distribution infrastructures, and it is also regarded as a new the foundation and new power motion for promoting economic development and industrial revolution, realizing sustainable development. The background and driving force for putting forward smart grid mainly derives from 4 aspects: facing the challenges from the rapid growth of the scale of renewable energy power generation like wind energy and solar energy; adapting to the power consumption structure change of electric vehicles and distributed generation, etc.,; the demand from aging power grid equipment and its upgrading, and the internet economy's infiltration of the real economy represented by the energy system and promotion from the new industrial revolution[1].

With the rise development of the smart grid in 2009 trend, both the State Grid Corporation of China (the State Grid Corporation of China，SGCC) and the China Southern Power Grid Co., Ltd. (CSG) put forward and formulated smart grid development plans in 2009 and promoted them comprehensively. Smart grid development in China can be divided into three stages: the initial stage (2009-2010), the comprehensive construction stage (2011-2020) and the improvement stage (2021-2025),), which covers various fields such as power generation, power transmission, power transformation, power distribution, power consumption and power dispatching. By the end of 2014, the State Grid Corporation of China SGCC had arranged 38 kinds of and 358 smart grid projects accumulatively, of which 32 kinds and 305 projects have been completed. The automation, interaction and information levels of the power grid have been improved greatly. It has a remarkable effect for supporting the full consumption of renewable energy, improving the flexible control capability of power transmission and the distribution network, meeting users' diversified load demands, ensuring safe, clean, economic and effective operation of the power grid. We have overcome a series of major scientific and technical problems on renewable energy integration, smart power transmission and transformation, smart power distribution and consumption, smart power dispatching and control systems, and information and communication platforms during smart grid practice, and obtained abundant research results and practical experience[2].

2. Key Renewable Energy Integration Technologies

By the end of 2014, China's installed wind power capacity reached 95.81x104kW, ranking first in the world, its installed photovoltaic capacity reached 26.52x104kW, ranking second in the world, second only to Germany. About 80% of the wind power sources are distributed in the "Three Norths" regions, namely, Northeast, Northwest and North China, and about 60% of the photovoltaic power sources are distributed in the Northwest region. Large-scale renewable energy is hard to be consumed locally, and the development of remote and large capacity power transmission technology is required to transmit clean power to the load centers of the mid-east region. In addition to the development of UHV AC and DC transmission technology, solving the problem of intermittent energy forecasts and energy storage technology is of great significance in the integration of large-scale renewable energy[3].

2.1 New energy grid-connection and forecast technology

New energy forecast research and application work was started abroad in the 90's of the last century. The earliest research organization is RisØ National Laboratory of Denmark, later, countries with fast new energy development such as Germany, Spain and America started related research. New energy forecasts are made on the basis of historical data, numerical weather prediction, real-time meteorological and power data, etc. The physical forecast method, statistical forecast method and mixed forecast method were put forward by various research organizations abroad and used extensively. New energy forecasts started late in China, but develop fast. As for wind power forecasts, the China Electric Power Research Institute researched and developed a wind power forecast system with a short term and ultra-short term forecast average error less than 9%, which is of an advanced, international level. As for solar power generation technology, the China Electric Power Research Institute put forward a forecast method considering cloud layer cover, and ultra-short term power rapid fluctuation was realized with overall forecast errors of less than 10%. By the end of 2014, the SGCC had deployed wind power forecast systems in 20 provinces (including autonomous regions and direct-controlled municipalities) and deployed photovoltaic generation power forecast systems in the Gansu, Ningxia and Qinghai provinces. Besides, distributed generation power forecast systems have been deployed in cities whose installed distributed generation capacity is larger than 1% of the local annual maximum load[4,5].

New energy connections and forecast technology will put effort into improving the accuracy of numerical weather prediction, focus on researching a numerical weather prediction dynamical downscaling method that can simulate a local effect in new energy development area in detail, fast assimilation method for multi-dimensional observation data and optimization for the parameterization scheme of boundary layers, etc. Meanwhile, cluster forecast algorithms facing new energy clusters will be researched to solve the problem that the forecast algorithms of single new energy stations cannot quickly meet the modeling demand of a full cover, large-scale new energy base. In addition, aiming at the rapid development of distributed new energy, technologies like smart modeling and on-line optimization will be researched[6].

2.2. Energy storage technology

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Energy storage technology is of strategic significance to solve the power generation and connection problem of large-scale renewable energy, which can be divided primarily into mechanical energy storage, electromagnetic energy storage, electrochemical energy storage and phase change energy storage[7,8].

Common mechanical energy storage includes pumped storage, compressed air energy storage and flywheel energy storage, etc. Pumped storage is the most conventional mechanical energy storage method, which has a history of over 100 years. The total installed capacity of mechanical energy storage reached 21.81x104kW in China by 2014. Currently, there are no large capacity compressed air energy storage projects which have been put into operation, while there are 2 large power stations that have been put into commercial operation abroad in Germany (with more than 30 years' history) and America (1992). The 3rd compressed air energy storage power station in the world with the largest installed capacity of 2.7x104kW is under construction in America.

The power and energy of electrochemical energy storage can be allocated flexibly according to different application demands with fast response speeds, which is not restricted by external conditions like geographical resources, and applicable to large scale applications and mass production. However, problems like limited service life and high cost are required to be solved at present. Common electrochemical energy storage includes lithium ion batteries, flow cell, sodium-sulfur cell, lead-acid cell and hydrogen energy storage, etc. So far, various battery energy storage pilot applications exist in China. The largest of all vanadium redox flow battery energy storage systems in the world was installed in the Woniushi Wind Farm in Liaoning Province. We have a good foundation on making water-electrolytic hydrogen technology, but hydrogen energy storage technology is still in the research stage instead of being put into operation. Meanwhile, the hydrogen cell vehicle fields of Japan and Germany have entered the commercialization stage.

Electromagnetic energy storage includes superconducting electromagnetic energy storage and super capacitors, etc. Electromagnetic energy storage is able to store energy for a long time without energy loss, featuring high store energy density and millisecond response time, with a conversion efficiency over 95% and infinite times of circulating charge and discharge, but with high cost.

Phase change energy storage includes molten salt energy storage, ice storage and heat storage electric boiler energy storage, etc. There are pilot applications of projects with molten salt or heat mediums in the Northwest and Northeast regions of China with abundant new energy resources. Table 1 presents the main energy storage demonstration projects in China.

Table 1 Main energy storage demonstration projects in China

Type	Installation location of energy storage facility	Energy storage form	Energy storage power (MW)	Energy storage capacity (MWh)
Wind and photovoltaic power storage station	Zhangbei, Hebei Province	Lithium battery energy storage (phase I)	20	70
		Lithium battery energy storage (phase II)	50	175
Wind power storage station	Woniushi, Faku, Liaoning	All vanadium redox flow battery energy storage	5	10
	Wind Power Heat Supply Project in Taonan, Baicheng, Jilin	Heat storage electric boiler	18	—
Photovoltaic power storage station	Baineng Company in Haibei State, Qinghai	Zinc bromine flow battery energy storage	0.05	0.1
	Zadoi County, Yushu, Qinghai	Lead-acid cell energy storage	3	12
	Photoelectric power station in Delingha, Qinghai	Molten salt thermal storage and energy storage	10	—
Energy storage power station	Meizhou Island, Fujian	Lithium battery energy storage	2	4
	Bijie, Guizhou (under construction)	Compressed air energy storage	1.5	—

	Energy conversion comprehensive exhibition base in Caoxi, Shanghai	Sodium-sulfur cell energy storage	0.1	0.8

In general, the development of energy storage technology is not mature in China. The strategic position and frontier science property of energy storage technology determines the long-term property and persistence of technology research and the development process. Energy storage technology itself is the core for achieving innovation and breakthroughs in energy storage as well as the bottleneck restricting the large scale application of energy storage systems. It is required to develop long life, low cost and high safety energy storage batteries, and to solve problems such as how to strengthen and improve energy density, power density, response time and energy storage efficiency during the energy storage period. Comprehensive assessment in energy storage technology is a necessary condition to achieve marketization and scale, it is required to establish a detection and evaluation system for energy storage. Demonstration clusters of distributed energy storage power stations, megawatt hydrogen energy storage systems and gigawatt chemical energy storage systems are planned to be built in China by 2030.

3. Smart power transmission and transformation technology

Power transmission and transformation links are important links in power grid transmission and power switching, its intelligentization development is the key means to improve the grid company's operation and management efficiency, and it is the grid company's construction emphasis for smart grid[9].

3.1. Smart substations

Substations are an important parameter collecting point and control execution point in a power grid. We established a Digital Substation featuring the application of the IEC 61850 standard and electronic instrument transformer in 2006, and entered the smart substation stage in 2009, marking two batches of smart substation pilot projects. In addition, the construction of 6 new generation smart substations was launched in 2013, which represented the highest level of smart substations in China. Although the smart substation concept has not been put forward abroad, it is tending towards intelligentization. Electronic instrument transformers have a history of over 40 years, of which the ABB Company has more than 60 sets of optical transformers running on line. Substation automatic systems mainly adopt applications of the IEC 61850 standard. Technologies such as state monitoring and the equipment fault diagnosis expert system are adopted by intelligent analysis for the entire life-cycle management of key power equipment.

At the present stage, smart substations in China feature integrated equipment, digital collection, networked transmission and smart analysis. Overall technologies of smart substations, especially unified whole station information specifications, coordination and interaction with the power grid, and integrated innovation of equipment are in an internationally leading position. Chinese smart substations adopted a local level – substation area level – wide area level hierarchical protection and control system actively at the international level, established an integrated business system combining with information integration and intelligent decision making, put forward a new construction mode for substations consisting of modularized prefabrication, plug type connection and assembly type installation. Besides, new equipment such as substation-area protection control devices, smart integration secondary equipment, time delay marking switches and disconnecting circuit-breakers of integrated electronic instrument transformers were successfully developed for the first time at the international level[10].

The SGCC had built 1,527 smart substations ranging from 110 to 750kV by the end of 2014. Smart substations have a remarkable effect on reducing the land area and building area, improving construction efficiency, reducing operation and maintenance cost, energy conservation and environmental protection, etc. 110-750kV outdoor AIS smart substations save more than10% land area, 26% building area, 64%cabling, 30%concrete quantity of cable trench, 34% secondary cabinets, 40% construction period and 1-3% life cycle cost compared with conventional substations[11].

As for the short term, the emphasis has been put on popularizing the application of electronic instrument transformers and integrated disconnecting circuit-breakers in the substations of China, solving the long-term operational stability problem of electronic instrument transformers and further optimizing and promoting the performance and integration level of secondary systems. As for the long term, the target is to build up power electronic technology and superconducting technology-based smart substations on the basis of new equipment, new material and emerging technology; and develop new equipment such as superconducting transformers, superconducting fault current limiters, power electronics transformers, solid-state switches and photon protection devices through the ongoing, converging, forward-looking technical idea to achieve sustainable innovation.

3.2. Disaster prevention and mitigation technology for transmission lines

In recent years, lightning, ice storms, fires and other natural disasters have occurred frequently, resulting in increased probability of transmission line outages. LLS and early warning, ice monitoring and early warning, and melting, fire early warning and other monitoring and warning systems for disaster prevention and mitigation for transmission lines have played an important role in ensuring the safe operation of transmission lines.

China is the second country following the United States to obtain independent intellectual property rights in the technical field of lightning location system (LLS). Since 1993, when the first set of domestic LLS was put into engineering application in the Anhui Power Grid, LLS had covered the grid in 32 provinces and the vast majority of the land area, which was integrated into the distribution network in 2006. Our domestic LLS has achieved various practical indicators with the scale and technical level of the lightning monitoring network, including the lightning flashover detection rate of the distribution network at > 90% and the positioning error at <1km, ranked in the leading position among the rest of the world. The LLS is used to perform real-time measurement of thunder discharge. In order to grasp the movement and development trend of lightning in advance, the State Grid Corporation developed and established the lightning early warning system to provide over 2h lightning forecasts and 15-30min high-precision lightning disaster risk forecasts for the monitored and protected targets. The scheduling and operation and maintenance units are thereby allowed to adopt operation mode adjustment and other measures in advance based on the early warning information, which significantly reduces the power loss caused by lightning strikes. The first pilot project for the lightning early warning system was put into operation in 2013 in Jiangsu Province. During the "13th Five-year Plan" period, the regional lightning early warning network will be established in over 10 areas, targeting strategic substations and transmission channels, which are to be integrated into the national network[12-14].

The overall solution to icing disasters faced by the distribution network refers to the comprehensive solution achieved by integrating various technical measure systems including “Combat, Prevention, Melting and Elimination” in response to icing disasters. Countries suffering from serious icing disasters like Russia, Canada, the United States, Japan, Britain, Finland and Iceland started early in the study and application of icing disaster prevention measures for transmission lines. Since the ice storm in 2008, we have achieved significant progress in ice damage control, obtaining excellent performance in the engineering application. By 2014, more than 1,000 sets of "automatic icing monitoring systems" were applied, and the work of UHV line meteorological observation was carried out nationwide. The "Icing Forecasting and Early Warning Center of State Grid Transmission Lines" has carried out long, medium and short-term forecasting work against transmission line icing in 9 provinces across China covering Sichuan, Chongqing, Hunan and other southern provinces. Totally, 43 sets of DC ice melting devices have been applied nationwide, and the UHV DC ice melting device has been successfully tested in Hunan Province, and 60 sets of mobile, portable, fixed and other types of ice-melting devices have been applied for the rural power distribution network; 30 sets of charged thermal de-icers have been applied for substations; and the mechanical vibration de-icing technology has been applied for the 500kV Yaodian – Baijiachuan line. During the "13th Five-year Plan" period, the focus will be put on the promotion and application of DC ice melting devices over the UHV lines, and the ice disaster prevention and control technology will be implemented in a comprehensive manner over all the strategic lines in the severely affected areas.

The world has failed to develop distribution network-integrated fire monitoring and early warning technology until 2009, when the State Grid Corporation pioneered the development of the fire monitoring system for transmission lines, which was based on satellite remote sensing data. The Fire Monitoring and Early Warning Center was established in Hunan Province in 2013 to build the direct-from-satellite receiver ground station. The various technical indicators in the domestic fire forecasting and real-time monitoring are ranked as the world’s leader, with an accuracy rate of fire forecasting and fire point identification reaching

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92% and 90% respectively, which can be positioned to a specific pole or tower along a specific line, with the monitoring interval of infrared satellite reception being shortened to 20min. With regard to fire extinguishing technology, China has successfully developed efficient anti-resurgence fire-extinguishing liquid and portable HP water mist extinguishers, with an anti-resurgence capacity of 95%. We are the first in the world to build a charged long-distance high-lift mobile fire-fighting platform, with a lift limit of up to 500m, which makes it possible to carry out live-wire fire fighting for HV transmission lines. Hunan Province has been equipped with over 100 sets of anti-fire equipment, successfully fighting more than 130 fires on power lines, which prevented fire-induced tripping accidents on a considerable number of strategic lines. During the "13th Five-year Plan" period, fire monitoring and early warning subsystems for transmission lines will be established in 12 high-incidence provinces, along with the SGCC full-coverage fire monitoring and early warning system for transmission lines[15].

4. Smart power distribution and consumption technology

As the last stage in the power system – user cycle, the power distribution and consumption system is closely connected with the users, and is also the critical stage for ensuring power supply quality, operation efficiency improvement and innovative user service, attracting extensive international attention concerning smart grid construction.

4.1. Distribution Automation System (DAS)

Over a long period of application in foreign countries, distribution automation technology has been increasingly advancing, and in which the distribution automation coverage in France and Japan reached 90% and 100% respectively. Japan attaches great importance to the practicability of distribution automation systems, focusing on fast fault locating and isolation functions; while Europe and America focus on DMS with a wide range of functions by equipping the main station with a large number of advanced application and management functions[16].

The distribution network of Japan mainly relies upon a local recloser for fault treatment. The switch remote control rate of the distribution network in France is not very high, which narrows down the fault isolation area by combining remote switch control from the dispatcher with local operation of switch by personnel on site. It takes less than 3min for over 50% power systems in France to restore power after failure. In South Korea, it is 6min.

The base condition of the distribution network is weak in China, which was late in introducing DAS. By the end of 2014, the overall DAS coverage of the State Grid Corporation stood at 12.6%, covering 78 cities, 27,000×10kV lines, mainly concentrated in urban centers with relatively mature grid frame structures, among which the coverage of class A+ and A power supply areas stood at 53.4% and 31.5% respectively; that of the class B, C and D stood at 11.7%, 8.4%, and 2.8%. The average switching operation time for areas with completed DAS dropped to 8.3min from 36.9min before operation. The average time it takes for non-fault areas to restore power supply dropped to 11.4min from 81min before operation[17].

At present, the overall distribution automation coverage in China is far from what is required for achieving scale effect. That is why we plan to dramatically expand it during the "13th Five-year Plan" period to 100% by 2020. The scope of DAS construction in China covers: distribution automation of the main station, distribution terminals, feeder automation (FA), and communication channel construction. The principle of the master plan for construction is to build a DAS main station integrating cities and counties, and to build the DAS information exchange bus, in an effort to achieve data sharing and information exchange between various system platforms including EMS, PMS, GIS, and marketing and scheduling, so as to meet a wide range of business requirements covering scheduling control, failure study & identification and emergency repair command. Differentiated distribution automation configuration shall be realized for various power distribution areas, by adopting a ‘triple remote’ terminal and optical fiber communication system in class A+ power supply areas, achieving fully automatic centralized or distributed smart distributed feeder automation for the fast processing of failures. For Class A and B power supply areas, the "triple remote", "standard double remote", and "action-type double remote" terminals shall be adopted to achieve centralized, smart distributed or local-type recloser feeder automation, which can effectively shorten the fault-induced outage time. For class C and D power supply areas, two types of terminals, the ‘standard double remote’ and the ‘basic double remote (fault indicator)’, shall be adopted to achieve, based on actual needs, the local-type recloser feeder automation featuring the fault monitoring function.

4.2. Smart power consumption technology

The construction of flexible and interactive smart power consumption is an important task of the smart grid, including bi-directional interaction of information with electrical energy, encouraging power consumers to change their traditional ways of electricity consumption, actively participating in power grid operation, and realizing plug-and-play parallel operation mode for distributed generation and electric vehicles. At present, the smart power consumption practices in China give priority to power consumption information acquisition, Demand Side Management and the charge/discharge service network of electric vehicles[18].

The power consumption information acquisition system is the foundation and key to realizing smart bi-directional power consumption, including the construction of a master station, terminal & smart KWH meters, and communication channels, etc., realizing remote automatic meter reading, self-recharging, real-time power consumption monitoring, line loss monitoring, orderly power consumption management and other functions. China developed rapidly in terms of the technology standard specifications of power consumption information acquisition, and reached a leading level in the world with a large number of installed smart KWH meters and a large coverage area. By the end of 2014, there were 214 million applied smart KWH meters within the business area of the SGCC, 8.036 million sets of power consumption information acquisition systems, covering 220 million power consumers with an acquisition coverage rate of 51.4%. In the future, China will fully build a power consumption information acquisition system according to the construction requirements of “full coverage, full acquisition and full cost control”, and take bi-directional interaction smart KWH meters as the carrier to support a real-time tariff system, support businesses such as in the interaction of power consumers information, the mergence of distributed generations, and the charging and discharging of electric vehicles, and actively popularize the technology of “Integrating four meters” including the KWH meter, water meter, gas meter and heating power meter.

Demand Side Management (DSM) covers Time-of-Use tariff, peak load shifting, and energy-saving technology etc. Based on tariff and motivation, the Demand Response (DR) policy is an important measure to realize DSM. As China is influenced by the tariff policy, the present major measure of DSM is orderly power consumption, and DR policy is only applied in pilots with a small coverage area. In 2013, Beijing, Suzhou, Foshan and Tangshan were listed as the electric power DSM pilot cities by the National Development and Reform Commission. In 2014, Shanghai was also listed as the power DR policy pilot city by the National Development and Reform Commission, where the power consumers that initiatively cut down power loads were given a feed-in tariff, thus a maximum single load reduction of 55,000 kW in the summer of the same year was realized through the implementation of the DR policy. At present, DR policy pilots are also being conducted in cities like Beijing and Foshan, and a DR policy that covers the whole of Jiangsu Province for the first time is being conducted. The DR policy construction in Jiangsu Province took air conditioning that occupied about 30%-50% of peak loads as response load, and the response control of a 620,000 kW air conditioning load for 1,162 buildings was completed in 2015. In the summer of 2015, the maximum single load reduction amount reached 141,800 kW. As the adjustable load, the value of DR load in the electric power system will increase with the rising of ratio unadjustable sets. With the release of Several Opinions on Further Deepening the Reform of the Electric Power System (ZF [2015] No.9) and its supporting policies, the price/motivation oriented DR policy may become an important approach to solve the imbalance between power supply and demand as well as issues of batch-type energy power balance in China[19].

Since the development of electric vehicles is the key development direction of low carbon economy and new energy utilization in China, it has been incorporated into China's seven strategic emerging industries of new energy. At present, China is developing its battery charging and changing service network in a reasonable and orderly manner, by following the principle of “giving priority to quick charging, taking slow charging into account, guiding battery changing, and building an economical and practical network”. The battery changing mode is mainly applied to commercial and passenger vehicles in the public service category, among which the battery changing mode of commercial vehicles has successfully achieved its commercial operation in cities like Beijing, Tianjin, Nanjing, and Qingdao. In terms of the DC battery charging mode, the power density and charging efficiency of battery chargers are relatively low with vast volumes, having a definite gap between advanced foreign levels, but the AC battery charging mode is similar to advanced foreign levels. There are no independent operators of battery charging service networks in China today, while large and professional operators of battery charging service networks have appeared in America and Europe. By the end of 2014, electric vehicle ownership exceeded 120,000, only less than that of America, Europe, and Japan, ranking the 3rd in the world. 723 battery charging and changing stations and 28,900 sets of AC charging points have been built, and the expressway quick charge network along "Two longitudinal expressways and one transverse expressway" (i.e., Beijing-Shanghai Expressway, Beijing–Hong Kong–Macau Expressway and Qingdao-Yinchuan Expressway) has been built, thus forming the largest battery charging and changing service network of electric vehicles in the world. With the large-scale application of electric vehicles in the future, we should focus on the study and development of technology that realizes charge/discharge stations in different battery charging and changing modes like TC ,V1G and V2G; the energy and information interaction technology for battery charging and changing and grid control dispatching system; the non-contact charging and inter facing technology for electric vehicles; and the business operation mode of battery charging and changing service networks based on "Internet+".

5. Smart power dispatching and control system

The role of the power dispatching system to the whole smart grid operation control can be deemed as the nerve center. Based on the unified D5000 platform, the power dispatching system construction of the domestic smart grid focuses on building the following: Major and standby dispatching and control systems of different levels; dispatching data network; and secondary security protection systems.

The smart power dispatching and control system, horizontally integrated over 10 independent application systems of the dispatching center into a new power grid dispatching and control system, consists of one basic platform and four application parts (i.e. real-time monitoring and warning; dispatching plan; security verification and dispatching management). Meanwhile, vertical coordination and control for dispatching tasks of three levels as state, network and province are also realized, through which the real-time data, graphics and application functions can be shared on the whole power grid. In the smart grid dispatching and control system, key technologies for relevant large power grid matters (to meet dispatching demands of super-large power grid) like unified modeling, a distributed real-time database and real-time graphics remote browsing have been studied and appropriately solved for the first time in the world. A series of key technological problems related to the multi-level dispatching and coordination of large power grid, which includes smart warning and coordination control and full-coverage online security warning, have been surmounted. Furthermore, the security control coordination, overall economic dispatching and high level security defense have even reached a leading international level.

Our country has been constructing pilot projects of smart power dispatching and control system since 2009. Based on the D5000 platform, the SGCC built (separate) state dispatching systems, 27 province-level dispatching systems and 288 regional power grid dispatching and control systems by the end of 2014. The biplane of the backbone network of the dispatching data network, which is based on hierarchical virtual private networks (VPN), comprehensively covered the dispatching systems of all different levels by the end of 2014, with 43,375 nodes arranged in the dispatching data network. With 2,301 PMU equipment installed, and 98.6% coverage of substations over 500kV, the system became the largest power grid dynamic monitoring system in the world. Meanwhile, along with the research and application of the core technologies of distributed standby dispatching systems, a super-large distributed standby dispatching system has been built, which is coordinately operated by 32 standby dispatching systems above province-level and 199 standby dispatching systems for local dispatching[20].

In the future construction of smart grid dispatching and control systems, China also needs to learn more about the power grid characters of AC and DC combined grid, and improve the control level and absorption capacity of clean energy. Besides, the construction of technological dispatching means, which better fit the electricity market environment, shall be strengthened, and the interactive reflection capacity between substation and dispatching systems, and the dispatching and control level of the power distribution network shall also be increased.

6. Conclusion

Domestic smart grid construction has always been led by power grid corporations. Along with the issuing of national strategic directions on energy revolution and innovation-driven development by Xi Jinping, the General Secretary, in 2014, the government issued a series of policy measures, which include Guidance on Smart grid Development, Guidance on Active Promotion of Internet + Action Issued by the State Council, and Major Smart grid Work, to promote smart grid construction. Smart grid development is in a win-win situation, involving many parties like the government, power generation, consumer, power grid, equipment and other industries and is facing unprecedented opportunities and challenges. In the future, our country will focus on the following: breakthrough of high-capacity energy storage technology and flexible DC technology with HV networking; the further development of smart power transmission and transformation technology; and improvement of grid connection and integration technology for large-scale renewable energy resources. Meanwhile, electric power system reform will be used as an opportunity to mainly develop smart power distribution and consumption technology and to improve supporting communication information technology to smart grid. Furthermore, the innovation for business models in key fields, which include smart charging services for electric vehicles, coordination and operation of renewable energy power generation and energy storage, one-stop service for smart power consumption and virtual power plants, will be developed with the basis of demonstration projects, and that will create a good environment for ensuring sustainable smart grid industry development.

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