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Review

The Smart Grids in China—A Review

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Abstract: The concept of the smart grid has been gaining more and more attention worldwide since it was proposed by the U.S. Electric Power Research Institute in 2001. Recently, it has been propelled again by the promotion of low carbon economies in developing countries. To satisfy the exponential increase in electricity demand and alleviate environmental degradation caused by fossil fuel-based power generation, China has made great efforts in constructing a smart grid as a substitution of traditional energy-intensive power grid. In the 12th Five-Year Plan in particular, it was stated that emphasis should be placed on the development of renewable energy and smart grids. The objective of this paper is to provide an insight into the current research on smart grids, and shed light on the development of smart grids in China, based on the analysis of which, the obstacles and barriers in the development process are identified. Finally, policy prospects on the construction of smart grids in China are proposed from the aspects of technology, administration and management.

Keywords: smart grids; review; policy prospect; China

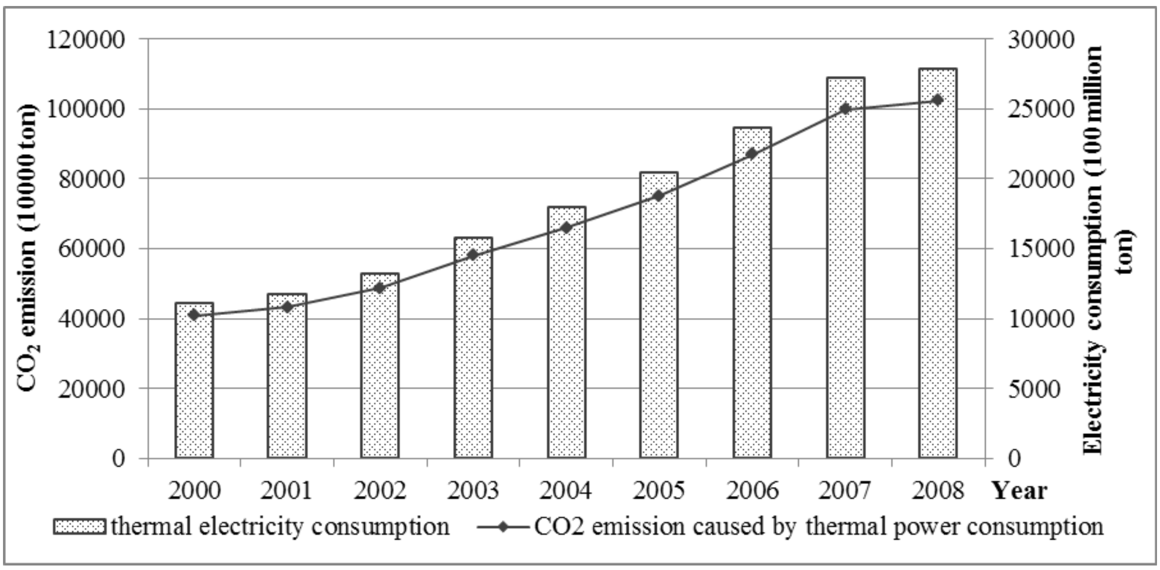
1. Introduction

The National Academy of Engineering in the USA has specified the electricity grid as one of the major achievements of mankind in the 20th century [1]. Sustained economic growth in China has driven an unprecedented expansion of the power sector over the past three decades. The proportion of energy consumed in electricity generation has reached 39%, as opposed to 20.6% in 1980 [2]. With an average growth rate of 11%, the total electricity consumption stood at 4,190 billion kWh in 2010. In the report "*The Twelfth Five-year Plan of Electricity Industry*" announced by the China Federation of Electric Power Enterprises, electricity consumption will amount to 5990–6570 kWh in 2015 with an annual growth rate of 8.5%, while power generation capacity will rise to 1.437 billion kWh [3]. The Chinese government has also made great efforts in the construction of energy infrastructure. Since 2000, the development of interconnections between regional grids has been accelerated. In 2005, the goal of forming a nationwide power gird was preliminarily achieved. At the same time, according to the distribution of resources and loads, China put forward its "*Power Transmission from the West to the East*" plan [4] and then carried it out step-by-step.

However, the rising electricity consumption and power grid construction raise questions regarding low energy efficiency and ageing assets, which affect the safety and reliability of the electricity system. According to the statistical data, in the power supply chain from primary energy use to efficient electricity consumption, about 80% of the energy will be lost due to the inefficiency of the infrastructure. In addition, security issues threaten the development of the power system. The more electricity power grids transmit, the less the stability of the power supply system will be. Even minor disturbances can make the system untenable. Taking the extremely snowy and icy weather in the southern part of China in 2008 for example, continuous snowfall largely destroyed the grid, leaving the transmission systems of 13 provinces paralyzed, the power supply of 170 cities cut off, and 36.7 thousand lines and 2018 substations disfunctional.

Another important issue of the power system in China is how to cope with climate change and resource constraints. With the increasing demand for electricity, electricity consumption-related CO_2 emissions have grown rapidly (Figure 1). Among all sectors concerning CO_2 emission, 40% of the total national CO_2 emission is attributed to the electricity industry in China. As economic output and energy consumption will continue to increase in the future, developing a power system with high efficiency and low carbon emissions is of great significance for the healthy development of the electricity industry.

Figure 1. Electricity related CO_2 emissions in China from 2000 to 2008.



The development of smart grids has attracted considerable interest from fields as diverse as economics, sociology and electrical engineering [5]. Clastres [6] provided a preliminary overview of possible solutions to encourage the emergence of new smart grid technologies. Nair and Zhang [7] reviewed the development of electricity grids in New Zealand and identified future opportunities and policies concerning intelligent grids. Mah *et al.* [8] examined the motivations, processes and outcomes of the development of smart grids in South Korea through the perspectives of governance and innovation systems. Ipakchi [9] presented some emerging smart grid applications and discussed information system requirements for a broad-base application to the smart grid. Zio and Aven [10] looked into the future world of smart grids from a rather different perspective of uncertainties and the related risks and vulnerabilities.

Smart grid technologies, including power generation, transmission, transformation, distribution, storage, and consumption, the focus of smart grid development, have been widely discussed. Järventausta *et al.* [11] investigated the general aspects of smart grids and focused on smart grid features at a distribution level, such as interconnection of distributed generation and active distribution management, using automated meter reading (AMR) systems in network management and power quality monitoring, application of power electronics in electricity distribution, plug-in vehicles as part of smart grids, and frequency based load control as examples of interactive customer gateways. Blasques and Pinho [12] proposed a demand-side management model integrated to a metering system for hybrid renewable energy systems in a micro-grid configuration. In Depuru *et al.*'s research [13], they discussed various features and technologies that could be integrated with a smart meter, outlined various issues and challenges involved in design, deployment, utilization, and maintenance of the smart meter infrastructure, and explained the importance of introducing smart meters in developing countries. The status of smart metering in various countries was also illustrated. Wissner [14] gave an overview of the options that information and communication technology (ICT) offered for the restructuring and modernization of the German power system. Gao *et al.* [15] conducted a systematic review of communication/networking technologies in smart grids, including communication/networking architectures, different communication technologies that would be employed into these architectures, quality of service (QoS), optimizing utilization of assets, control and management, *etc*. Giordano and Fulli [16] presented a systemic perspective aimed at establishing technical and economic synergies that may improve the business cases of individual different smart grid technologies and contribute to reverse the consumption-driven paradigm of the electricity sector. Brown [17] investigated the role of standards, related training and certification for the electric vehicle. The impact of smart grid on the economy, society, power grid security and climate change were also evaluated in previous researches [18–22].

There are also research works on power grid systems conducted in China. Ma [23] summarized key milestones of the development of on-grid electricity tariffs in China, examined the tariff-setting mechanisms of coal-fired power plants and renewable power generation, and analyzed the factors associated with the adjustments of the tariff levels. Options for further reform and more effective electricity pricing were discussed. Zhu *et al.* [24] described the development of China's power industry, including present situation, environmental influences and potential benefits of regional power grid interconnections. Zhou *et al.* [25] provided a comprehensive introduction to the current status and the future development of the power transmission systems and grids. Luo *et al.* [26] established the evaluation index system for the power grid enterprise's investment returns, based on which, a comprehensive appraisement method was proposed according to the characteristics of power grid enterprises. Wu *et al.* [27] analyzed the smart grid informatization construction system in China, and showed the contents of informatization construction from three different dimensionalities: the information hierarchy, power industry chain and business type.

Although studies on power grids of China have been conducted from the aspects of on-grid electricity tariffs, power grid interconnection, transmission system, cost benefit analysis and renewable power, most work focused on one aspect of smart grids [28–30]. In this paper, we intend to conduct a literature review to acknowledge the evolution and current status of smart grids in China. By identifying current characteristics and shortages of smart grid, policies that can be applied in the future smart grid development are proposed to guarantee the grid security and efficiency. The rest of the paper is organized as follows: Section 2 probes the definition and characteristics of smart grids. Then, Section 3 provides an overview of the background and history of smart grid development in China. Subsequently, barriers that obstruct the development of smart grids are identified. Based on the current level of smart grid development, which is analyzed in Section 3 and Section 4, Section 5 proposes policies that can propel the development of smart grids from different aspects. Finally, conclusions are drawn in Section 6.

2. Defining Smart Grid

Owing to the complexity of power systems, the definition of a smart grid varies. In fact, smart grids are not only a kind of technology, but also a series of new technical and institutional innovations that can make the power grid more efficient, cleaner and smarter. Therefore, different stakeholders have different visions and assumptions of what is and is not included in smart grids. As defined by the European Regulators' Group for Electricity and Gas (ERGEG), a smart grid is an electricity network that can efficiently integrate the behavior and actions of all users connected to it like generators, consumers and those that do both—in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety [31]. In the definition of the U.S. department Of Energy (DOE), the aims assigned to a smart grid are specified in more detail, and a smart grid must integrate the characteristics or deliver the performance described below: "self-healing from power disturbance events; enabling active participation by consumers in demand response; operating resiliently against physical and cyber attacks; providing power quality for 21st century needs; accommodating all generation and storage options; enabling new products, services, and markets; optimizing assets and operating efficiently" [32]. In China the smart grid concept focuses on all sections of the power system, including smart power generation, transmission, deployment, usage and storage. Thus, we define smart grids in China as an integration of renewable energy, new materials, advanced equipment, information technology, control technology and energy storage technology, which can realize digital management, intelligent decision making and interactive transactions of electricity generation, transmission, deployment, usage and storage. Compared with traditional power grids, smart grids are both economically efficient and environmentally friendly. The comparisons of parameters are listed in Table 1.

Table 1. The differences between traditional power grids and smart grids.

Traditional Power Grids	Smart Grids
Mechanization	Digitization
One-way communication	Two-way communication
Centralized power generation	Distributed power generation
Radial topology	Network Topology
A small number of sensors	Sufficient sensors and monitors
No automatic monitoring	Automatic monitoring
Manual recovery	Semi-automatic and automatic recovery
Pay attention to failures and disruptions	Adaptive protection measures
Manual checking equipment	Remote supervisory controlling equipment
Handling emergencies through staff and telephone	Decision support system and reliable prediction
Finite control	Pervasive and intensive control system
Limited pricing information	Complete pricing information
Fewer user options	More user options

Obviously, compared with traditional power grids, smart grids excel in many aspects. In brief, smart grids can improve energy usage via: (1) energy feedback to users coupled with real-time pricing information and from users with energy consumption status to reduce energy usage; (2) real-time demand response and management strategies for lowering peak demand and overall load through appliance control and energy storage mechanisms [15]; (3) integrating renewables and energy storage in electricity networks, while optimizing their use and contribution to system services and the whole sale markets; (4) promoting innovation, new energy products and services related to load handling, and (5) anticipating outages [6], with the necessary upgrading or maintenance of self-adaptive networks.

Owning to the advantages of smart grids, they are now attracting more and more attention worldwide. In the United States and the European Union, elements of the smart grid are being identified and researched by organizations representing governments, national laboratories, the private sectors, various trade associations and the academia. This concept was even listed in the U.S. Energy Independence and Security Act [33] announced in December, 2007. In Italy, the "Progetto Telegstore" initiative begun in 2002, and resulted in the installation of over 30 million smart meter points covering almost 100 households. In Norway, Sweden, Finland and Demark [34], penetration rates of smart meters have risen by above 50 percent, with continued increases expected. As a result, it is observed that a trend of researching on smart grids is emerging.

3. The Evolution of Smart Grids in China

The impact of smart grids on CO_2 emission mitigation remains ambiguous and needs to be further investigated. A converse possibility is that the rapid grid development may contribute to the rapid growth in CO_2 emission in China. However, as smart grids can distribute renewable energy, connect more renewable power to the grid, and thereby enlarge the proportion of renewable energy in the total energy consumption, the spread of smart grids may, at least in this aspect, significantly propel technological innovation, clean energy consumption and low-carbon transition in China. Recently, China has made important breakthroughs in the innovation of smart grids at both the practical and theoretical levels.

With the successful implementation of the 11th Five-Year Plan, the scale of the power grid of China ranked the first in the World in 2011. In addition, technological breakthroughs in ultra-high voltage electricity transmission have been made. Moreover, CO_2 emission mitigated by the electrical industry has amounted to 0.174 million tons. In the next five years, the government will continue to lay more emphasis on the construction of smart grids. Thus, a review on the evolution of smart grids from the aspects of technological innovation and organization would be instructive for future policy making.

3.1. Technical Innovation

In the 1990s, the concept of "Digital Power System", which is an early form of state grid, was first proposed by Lu and Mei [35] in their research of "*Basic research on vital scientific problem with collapse prevention and optimal operation of large scale power systems*". In 2004, fundamental research to improve the reliability of large interconnected power systems and apply distributed computing to real-time simulation of the entire power grid was conducted. The East China Power Grid (ECPN) first carried out its feasibility study on smart grids in 2007, which advocated promoting deployment of power systems, constructing digital substations and building a unified enterprise data platform. This effort, which aimed at promoting the level of power grid security and management ability, marked the first step towards the implementation of smart grids. Another important research concentrated on power distribution in 2008 explored distributed uses of nonrenewable energy. Recently, an investigation about key technologies in smart grid construction was undertaken by the National Science & Technology Board, Chinese Academy of Sciences and Chinese Academy of Engineering.

China has formed relatively mature technologies of automated measuring systems and gained practical experiences in technologies such as peak load shifting, real-time monitoring and remote automatic meter reading [36]. In the communication network aspect, China has already realized comprehensive network coverage and established an integrated power communication network service platform based on an optical data network. Approaches applied currently include power line carrier communication, wireless communication, and communication through electric cable and satellite [37]. Another remarkable accomplishment is the wide application of information-based software, especially the systems related to power deployment automation, such as the distributed control system, relay protection system and power grid stabilization system [27]. It is obvious that the improvement on power grid deployment automation in China is prominent, with 32 provincial network deployments, 240 regional network deployments and 500 county-level network deployments been equipped with computer monitoring system. The majority of provinces have passed the SCADA application checking. More than 10 wide-area measurement system (WAMS) [38], 1,000 PMUs have been accomplished, covering all 500 kV substations and major power plants nationwide.

3.2. Piloting the Smart Grids

Smart grids have great potential in revolutionizing the way we produce and consume electricity, but the benefits of smart grids, which include many new elements, remains untested. Conducting pilot projects [39] is now regarded as an effective way to identify the likely impact of the smart grid on customers, utilities, and society as a whole.

Aiming at applying smart grid technologies to practice, some regions of China such as Jiangsu and Shanghai began their pilot construction of power information collection system encompassing loading management and meter reading technologies starting in the 1990s, and have accumulated abundant practical experience on demand side automatic meter reading, interoperation and demand side response. In the last two years, the State Grid Corporation of China (SGCC) has launched 228 pilot projects covering 21 technological categories. Breakthroughs have been made in six areas, including smart substation, automatic power distribution, power consumption information collection, electric vehicle charging infrastructure, technical supporting system on smart grid deployment, and power fiber to the home (PFTTH). In 2011, the construction of the Integrated Demonstration Project of Smart Grid in Sino-Singapore Tianjin Eco-City, which has a wide coverage and is the most complete pilot project, has been accomplished. Some smart grid pilot projects on power transmission, distribution and transformation are listed in Table 2.

Table 2. Pilot projects of smart grid in China.

Year	Regions	Pilot Projects
2010	Yangzhou	Yangzhou city of Jiangsu Province was selected as the first "smart grid industrial base" by National Science and Technology Ministry in its "Torch Program" in August, 2010.
2011	Tibet	The Qinghai-Tibet cross DC networking engineering has been accomplished in the end of 2011.
2011	Tianjin	The construction of the Integrated Demonstration Project of Smart Grid in Sino-Singapore Tianjin Eco-City has been accomplished.
2012	Fujian	Piloting on 13 smart grid programs including distribution network, electric vehicle charging infrastructure, and smart community. In addition, 17 smart substations will come into construction and 4 smart substations will be put into operation. Newly stalled smart meters are expected to reach 1.78 million, with full-scale automatic information collection realized.
2012	Shandong	The online monitoring device will be installed to supervise the performance of 220 kV and above electrical transmission and transformation equipment. In addition, the construction of 6 existing charging stations will be accelerated and 17 new ones will be put into construction.
2012	Jiangsu	In 2012–2015, Jiangsu province will construct 580 smart substations of 110 kV or more and transmission line of more than 13500 km.
2012	Liaoning	Constructing a high informationalized, automatic, interactive smart grid which is adaptive to the large scale access of nuclear, thermal and wind power, and is satisfactory to the requirement of AC/DC power transmission.
2012	Guangxi	Guangxi Grid is and will be dedicated in rural power grid reconstruction, and is ambitious in building up a set of demonstrating counties, power supply administrations, and substations with smart grid distribution system, digital and unattended substation, and remote meter reading system. Now, 184 demonstration projects have been approved and initiated.
2012	Xinjiang	During the 12th Five-Year Plan period, thousands of kilometers of power grid will be built, connecting each hydroelectric and thermal power base.
2012	Shanxi	Piloting on smart substation, power consumption information collection, smart community, electric vehicle charging infrastructure, and PFTTH. 1.2 million Smart Meters are expected to be installed.

3.3. Policy Support and Standardization

With the target of building a powerful electric grid with ultra-high voltage transmission corridors and increasing the integration of renewable energy resources, the construction of smart grids has been included in national development planning and related government documents. For example, "*The 12th Five-Year Plan on National Economic and Social Development*" proposed by National People's Congress has explicitly set up the goals of strengthening power grid construction and accelerating smart grid development. In another government document, "*Decision of the State Council on Accelerating the Fostering and Development of Strategic Emerging Industries*", the requirement of speeding up the construction of smart grids and operating systems to adapt to new energy development was put forward. In addition to national level policies, some local governments had also laid out specific plans on smart grids, such as the "*Smart grid industry in Jiangsu Province Development Plan Outline*" enacted by the government of Jiangsu Province.

The standardization of smart grids has already been started in China by a leading group organized by standardization administration and the National Energy Bureau. This organization is working step by step on the standardization task with a coordinated working mechanism.

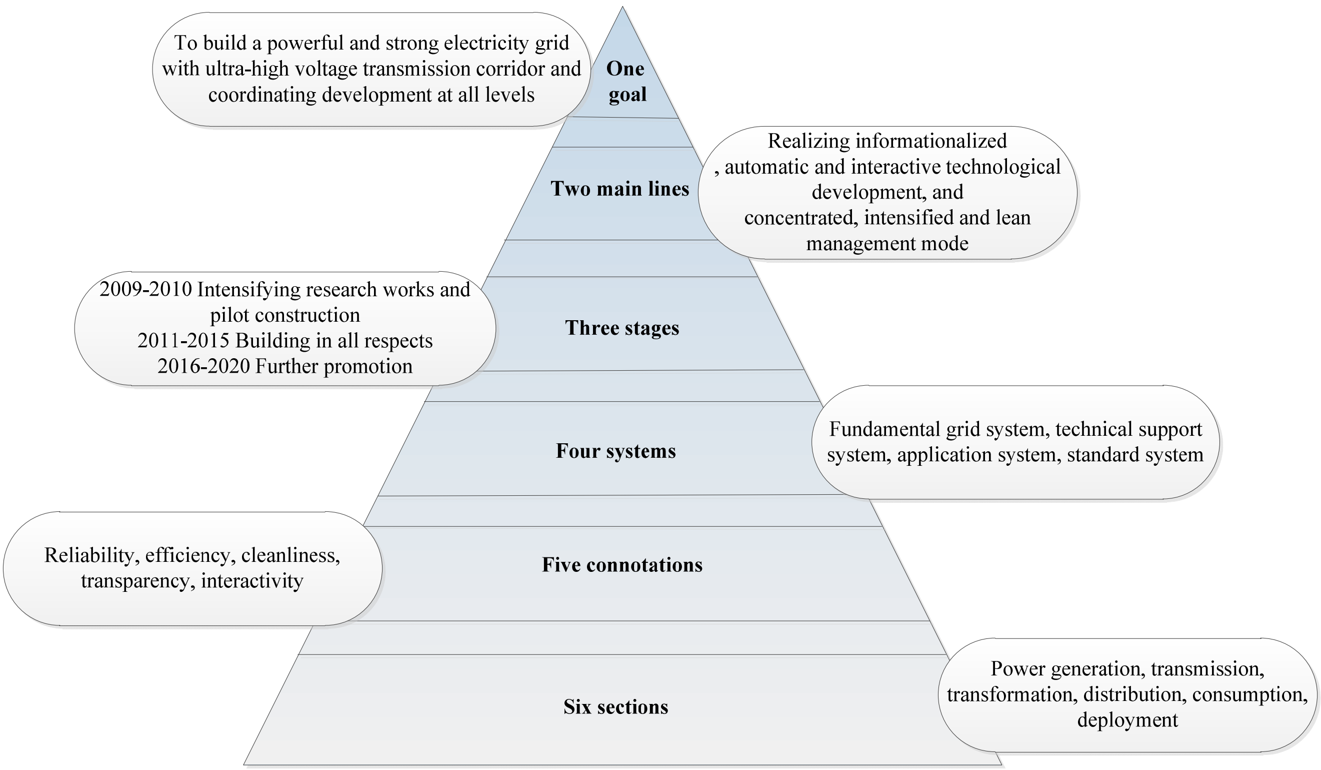
3.4. Implementation and Management

Unlike other countries the implementation of smart grids in China, where the government plays a leading role, is quite different. There are only two grid companies: the State Grid Corporation of China (SGCC) and China Southern Power Grid (CSG). These two companies take charge of almost all power transmission, distribution, metering activities in China. The SGCC is a backbone state-owned enterprise covering 26 provinces, municipalities and autonomous regions of the northern China, while the CSG serves five provinces in the south, including Guangdong, Guangxi, Hainan, Yunnan, and Guizhou. As they serve different regions, they don't need to compete with each other.

As the largest power network operating company in China, SGCC is the main promoter and executor of smart grid applications. At the International Conference on UHV Transmission held in 2009, a strategic framework of smart grid development with one goal, two main lines, three stages, four systems, five connotations and six sections was put forward, as shown in Figure 2. In this pyramid strategic framework, the top layer is the goal of smart grid development, *i.e.*, building a powerful and strong power grid with ultra-high voltage transmission corridors and coordinating multi-level grid development. The second layer is the technical and managerial guidelines of smart grid development. In the technical aspect, efforts will be made towards building an informationalized, automatic and interactive smart grid. In addition, concentrated, intensified and lean management mode is expected to be established. In the third layer, the smart grid development planning which is divided into three stages is introduced. The emphasis of the first stage (2009–2010) is R&D on technical innovation and pilot projects. Now, the task of the first stage has been accomplished, with a plan, two fundamental construction programs, 21 demonstration projects, and 10 specific research projects finished. In the second stage (2011–2015), smart grids in China will be largely promoted. Specifically, the construction of UHVDC and power distribution network will be accelerated. In the last stage (2016–2020), the resource distribution ability, stability, interactivity between the power grid and the consumer should be enhanced, and a strong smart gird will be finally built. The fourth layer is the "Four system" of strong smart grids, including fundamental grid systems, which are the foundation of realizing "strong", technical support systems with advanced communication, information and control technologies that make the grid smarter, application systems that make the largest use of power resources and provide services for consumers, and standardization systems, *i.e.*, the technical and managerial standards and evaluation systems. Five connotation in the fifth layer underlines the implications of smart grids, *i.e.*, reliability (strong grid structure, transmission ability and reliable power supply), efficiency (efficient grid operation and power transmission, high economic profit), cleanliness (large proportion of renewable energy utility in terminal energy consumption), transparency (transparent and shared information of grid, power supply and consumer, non-discrimination and fair opening of electric power network), and interactivity (active participation of power enterprises and consumers in regulating grid operation). At the bottom, all sections of the power system including generation, transmission, transformation, distribution, consumption and deployment are considered in the smart grid development.

To enhance the development of standardization, the SGCC started establishing a technical standard system for smart grids. Until now, fifteen technical standards including "*Standard Technology System Planning for Strong Smart Grid*" and "*Technical Guidelines for Intelligent Substation*" have been established. Thus, a series of technology standard systems were primarily formed to instruct projects implementation. The applications of smart grids were also paid great attention. Nine demonstration projects like the integrated smart grid demonstration projects in Shanghai Expo Park and a 110 kV intelligent substation in Beichuan, Sichuan have been completed.

Figure 2. The strategic framework of strong smart grid development.



Simultaneously, another important power grid operator, CSG, has also put forward its overall objectives and principles concerning smart grid development. To accomplish these goals, CSG has already made relevant strategic planning, attaching great importance to 18 smart grid technologies, and started several pilot projects. To build an automatic distribution management system with technical features of remote management, remote signal and remote control, two important projects on intelligent network distribution were constructed in Shengzhen and Shanghai. In the aspect of intelligent substation construction, CSG has built Sanxiang intelligent substation in Zhongshan City to research into wide-area information monitoring and control. Multi HVDC coordinating and control system developed by CSG has also been put into operation. The Longgang renewable energy application base was built to experiment on developing renewable power and connecting it into grid. Based on 863 programs of distributed power supply in Fushan and a micro-network project conducted by Yunnan EPRI, research on technology development of megawatt gas turbine CCHP and efficient access technology of distributed gas turbines, PV and energy storage systems are being gradually carried out.

From the review of the status of China's smart grid construction, a conclusion could be drawn that China has obtained prominent achievements in the field of smart grids and is catching up with developed countries like the U.S. and E.U. A solid foundation has been laid in the early research work and power infrastructure construction. However, as China is still in its primary stage of smart grid construction, barriers and problems that obstacle the implementation and application of smart grid are inevitable.

4. Barriers

Despite the great accomplishments achieved, we should be aware that smart grids are still a relatively new concept. To realize the scale-up and industrialization of smart grids, there is still much room for improvement. Four major barriers encountered in the development of smart grids in China are listed below:

(1) Unified goals and emphases on smart grid development have not been established yet in China. In the U.S., the development of smart grids mainly focuses on upgrading the infrastructure, as well as promoting the exploitation of renewable energy, distributed energy and green cars. In addition, the installation of smart meters in the U.S. is also emphasized, with government financial assistance that has funded more than 100 smart meter programs. Twenty five million smart meters are planned to be installed in 2013, which is three times the number in 2009. The key issues affecting smart grids in Europe are the integration of wind power and enhancing demand side management. Japan is dedicated in integrating PV power, wind power and distributed power into the grid and promoting the development of electric vehicles and micro-grids. A clear objective should be designated in China to guide the development orientation of smart grids.

Although smart grids have been developing rapidly in China, there is still no common understanding on the concept and implication of smart grids in the power industry. Controversies and basic disagreements on the key points of development widely exist, such as what benefits can be brought about by smart grids, how much the smart grids may cost, and which problems could be solved by smart grids. In the future development of smart grids in China, the government as well as researchers should dedicate great efforts to tackling these problems according to the specific situation of China.

Recently, a residential electricity price ladder program, which specified that "80% of household electricity prices remain stable, electricity consumed surpass the regional average must be paid according to the the second and third gear standard with unit of electricity price increasing 0.05 yuan and 0.2 yuan" was proposed in China. This program will help improve China's tariff structure and control electricity consumption. To guarantee the implementation of a residential electricity price ladder program in China, smart meters, a measurement of electrical energy consumption, can provide additional information compared to a conventional energy meter and read real-time energy consumption information. In fact, the residential electricity price ladder program can't be implemented until the smart girds are popularized in China. As a result, China should focus on promoting the application of smart meters referring to the experiences of U.S. by ways of enhancing financial subsidy.

(2) The ancillary facility cannot fit in with the requirements of smart grids, and key smart grid technologies are still immature. There is still a long way to go in some areas which are reflected in the following: firstly, most current equipment can't satisfy the demand of informationization, automation and interoperability. Secondly, the equipment specifications and standards are inconsistent, and are poorly interchangeable, which need further promotion. Thirdly, the core technologies of key equipment haven't been fully mastered. Fourthly, most of the existing automatic distribution devices are designed as one-way electricity flow for limited household consumption. These devices can't meet the demand for interoperability. In addition, smart grids in China are still in the technology R&D stage, with immature energy storage technology, system integration technology and new material technology. As distributed energy hasn't been substantially applied, large-scale development of smart grids is still hindered by a lack of external conditions. A full estimation of the immaturity and uncertainty of smart grids is needed, and the government should avoid promoting plans in the context of unclear market selection.

(3) The current power operating mechanism can't fit in with the demands of smart grid development. Smart grids are not only a technical innovation, but also an institutional innovation. Whether new technologies can create value is determined by the fact whether the power grid operation can adapt to the development of productivity, because advanced technologies need advanced production operation mechanisms to support them. Institutional innovation of smart grids includes reforms of the electricity market, regulation regimes and some political issues. Firstly, since a basic principle of smart grids is to improve energy management and consumption efficiency by making the customer's load and the smart grid interact through smart pricing and automatic control, the implementation of these measures requires a quite mature electricity market. In a word, the large scale implementation of smart grid technology, especially customer participation, depends on the development of power marketization, without the support of which, intelligent measures such as demand side real-time management can't be implemented.

Since reform and opening up was conducted by Chinese government, the reform of power operating mechanism has gradually deepened. However, there are still many problems with the regulation regimes of the power system. Although the separation of government and enterprises, power plants and power grids have been realized, there is a lack of market competitiveness and customer choices in power transmission, distribution and selling. Electricity pricing still depends on administrative approval, and a reasonable and efficient dynamic electricity pricing system which is the foundation of interoperability hasn't been formed. From the perspective of current government management, the existing regulation systems are mostly oriented by low-cost and extensive servicing. Although most of these regulation regimes are reasonable, some of them are not conducive to the transition to smart grids.

Political and jurisdictional system is the guarantee of smart grid development. Although some relevant policies on renewable energy and power grid construction have been enacted, a well-established political framework hasn't been formed. Thus, a government oriented development mode of smart grids should be established to create a healthy political environment for the promotion of smart grids in China.

(4) The standards and business modes of smart grids have not been established. Electricity generation, transmission, distribution, metering of traditional power systems are designed separately. In order to connect them together in the future, a uniformed standard should be established. In addition, as smart grids cover a wide outreach, if there is no consensus standard, we can't attract inputs and investments from stakeholders that have different purposes.

The business mode of smart grids is another key issue besides standardization. How to find an appropriate mode that could create profit and make the power company, equipment manufacturers, service providers and customers all win is a determining factor of smart grid generalization. Currently, with no available solution to the business mode of smart grids, smart grids cannot be applied on a large scale.

5. Policy Prospects

Smart grids involve a series of new technologies which have great potential in the future power grid development. To build a secure, economic, clean, transparent and compatible power grid in the future, we should take measures to propel the development of smart grids. We have reviewed and summarized some policy recommendations from national plans, policies, and reports related to smart grid development, such as "*China's Twelfth Five-year Plan (2011–2015)*" and "*White Paper on Green Development*" enacted by the SGCC, to tackle the current obstacles and provide guidelines for the future smart grid development.

5.1. Planning for the Blueprint of Smart Grids

Smart grids are very professional technologies which involve a wide range of subjects. Thus, an overall design for practices in China should be determined to instruct the smart grid construction and avoid a waste of investment. This design must include components like strategic goals, principles, implementation details and long range planning. An appropriate working mechanism and organization should also been confirmed.

The emphasis of smart grid planning should focus on goals to be achieved as well as problems to be solved in the electricity and energy development process. The problems to be tackled urgently in China include [40]: (1) how to optimize the power grid structure and improve the stability of operation; (2) how to improve the electricity quality and power distribution reliability; (3) how to promote low carbon energy development and provide a supportive platform for large scale renewable energy use; (4) how to increase the efficiency of power assets; (5) how to adapt to the demand of large-scale access of electrical equipment, distributed power, electric cars and other new power sources.

To solve these problems, the 12th Five-Year Plan placed an emphasis on standardization, the development of major equipment, demand side response and the large-scale demonstration projects. A step-by-step smart grid development mode is suggested referring to the “Three stage” strategy proposed by the SGCC. Firstly, according to difficulties encountered currently, we should put forward a plan to guide the development of smart grids, following which, the development of key technologies and equipment as well as the pilot demonstration and standard establishment should be highlighted. Secondly, after summarizing the technologies and pilot projects, expanding the smart grid piloting projects around the whole China based on the characteristic of each region. The third step should focus on avoiding overlapping investment and introducing new technologies under a unified standard. Also, it’s necessary to maintain the existing smart grids and upgrade the technologies, ultimately building an integrated maintenance system.

5.2. Determining the Administrative Mechanism of the Development of Smart Grid

While the development of smart grids must rely on real market demands and follow the market operational mechanism, the innovation on business mode of power companies is strongly encouraged. The development of smart grids is a complex and systematic project, which calls for the coordination of government agencies, power grid enterprises, electricity generating companies, equipment manufacturers, information communication enterprises, research centers and end customers. To ensure smart grids operate well, we can organize a promotion group on smart grid development oriented by the government, in which, government departments, regulation institutions, industry associations, power companies, research centers are all involved to work closely to propel the development of smart grids [41]. This group is responsible for the following work: (1) working as a thought leader to make plans for smart grid development; (2) coordinating important issues in smart grid development; (3) organizing enterprises and research centers to enact technology standards; (4) monitoring important smart grid programs; (5) conducting smart grid R&D work and demonstration projects.

5.3. Perfecting the Policies Supporting System

Although many intelligent grid technologies such as distributed power generation, demand side management and micro-grid have been introduced to China, these technologies have developed slowly owning to the incomplete policy support system. As smart grids are in their early stage in China, systematic supporting policies should be put forward, especially policies on inputs of projects, program ratification, standards setting, electricity pricing mechanism and financial revenue [42]. These policies should be enacted to promote the development of the whole smart grid industry. Specifically, the government can increase R&D funds, support competitive research centers and enterprises to innovate on the R&D, and produce core products with technical advantages. Meanwhile, financial support and reduced taxes on demonstration programs should be strengthened to encourage the application of smart grid technologies. Electricity pricing policies as well as real-time and high reliability electricity pricing pilot demonstrations are also needed to form a market adaptive electricity pricing mechanism, and policies on the payback of electricity enterprises that invest in smart grid construction should be enacted.

5.4. Accelerating the Standardization Work

Since smart grids involve many industries and technical areas, a unified technology standard system is beneficial for the coordination of different industries and technical areas, and it is also a key factor for orderly development of smart grids [43]. This unified technology standard system can provide technical instructions for equipment manufacturers, system coordinator and power grid construction companies, and ensure the quality and speed of the development of smart grids. It can also efficiently guarantee the interoperability of electricity generating systems, power grids and power consumers. Led by the Chinese smart grid standardization group, the government should organize and complement the interoperation framework and accelerate the standard setting process.

5.5. Innovating Smart Grid Technologies

Chinese government attempts to include smart grid construction in "*National Science and Technology Development Plan*" and "*Major Scientific and Technological Project*", and build strategic alliances of smart grid technologies. In the 12th Five-Year Plan, we should pay more attention to key smart grid technologies, and produce more products, technologies and brands with indigenous intellectual property rights in important business and technology areas like stable running of power grids, large capacity and long distance transmission of wind power, new materials, large-capacity energy storage, electric vehicles, intelligent deployment of distributed power, gradually making China the leader in smart grid technologies. It is estimated that China alone will spend $60 billion over the next decade to reinvent its power transmission and distribution system into a modernized, smart grid [44]. Meanwhile, in order to strengthen and enlarge the professional team, on one hand, we should establish majors and institutions concerning smart grid to cultivate and foster professionals with solid backgrounds and outstanding skills; on the other hand, we should attract more experts on smart grids worldwide to dedicate themselves to the career of smart grid construction in China.

5.6. Promoting the Demonstration of Pilot Projects

As China is at the same starting line with the developed countries, there is little previous experience could be used for reference. In order to provide a reference for large scale smart grid construction, pilot projects should be carried out. Specific measures include both propaganda, education and the construction of demonstration projects, like increasing acceptance of the whole society for smart grid by means of introducing the role of smart grid in Energy Conservation and Emission Reduction, improving power grid reliability, and gradually starting the construction of smart building in government departments and power grid enterprises, as well as the pilot construction of smart cities in important cities. In the future, efforts will continue to be paid on smart substation, automatic power distribution, power consumption information collection, electric vehicle charging infrastructure, technical supporting system on smart grid deployment, and power fiber to the home (PFTTH).

5.7. Enhancing the Implementation Management

The construction of smart grids needs vast investments, due to the specificity of assets, the investments have a technological lock-in effect in the following decades, and all these investments and costs will be taken ultimately by electricity consumers by means of electricity fees. To guarantee the quality and profitable of smart grids, an evaluation standard is required to assess the costs and benefits of smart grid programs [45]. In addition, the enhancement of investments supervision and costs accounting can not only ensure the profits of power enterprises, but also benefits gained by consumers.

6. Conclusions

Low-carbon society construction is becoming a new approach to optimizing economic development, ensuring energy security and coping with climate change. A massive deployment of low carbon technologies is then absolutely needed to achieve the expected reduction in GHG emissions during the next fifty years. For the electricity system, smart grids which could promote efficiency and security, as well as realizing low-carbon economy, are attracting more and more attention in China.

In this paper, by meticulously analyzing the current status of smart grids in China from the aspects of technologies, research work, pilot regions and organizations, we concluded that China had already made great achievements on smart grid construction, and will play an important role in global smart grid development. Although China has reaped fruitful achievements, there are still obstacles that hold back the development of smart grids. The barriers could be summarized in the following four parts: (1) The development goals of smart grids haven't been identified in China; (2) The ancillary facilities can't fit in with the requirement of smart grids, and key smart grid technologies are still immature; (3) Current power operating mechanism can't adapt to the demands of smart grid development; (4) The standards and business modes of smart grids haven't been solved.

To overcome these barriers, we should make efforts from the aspects of technology, organization and management in the 12th Five-Year Plan. Moreover, along with the announcement of Chinese government that the proportion of non-fossil fuel energy is expected to grow to 15% of the total energy consumption in 2020, the development of smart grids will be accelerated to efficiently connect renewable powered electricity into the grid and realize the co-win target.

In addition, the final realization of smart grids still has a long way to go. In this process, government policies, investments even the technical maturity, economical efficiency, grid infrastructure and the habits of residents will exert a great influence on its development. To keep smart grids proceeding steady, we could divide the process into different stages with different emphases.

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