# Smart Grid in China: Development and Practice

**Zhenya Liu**
**State Grid Corporation of China**
**Xichang'an Avenue 86, Xicheng District, Beijing, 100031 China.**

## SUMMARY

Smart grid, also known as "Energy Internet", is backboned by robust grid network, integrated with modern grid technology, control technology and IT technology, and it connects large-scale energy bases, distributed generation and various customers. As a powerful comprehensive platform for energy conversion, efficient allocation and interactive services, smart grid bears a great significance as the catalyst for the 3rd industrial revolution. In recent years, China has carried out a lot of theoretical and technical researches on smart grid and formulated a relatively complete development layout and technical standard system for smart grid. A large number of smart grid pilot and demonstration projects have been constructed and put into operation regarding new energy integration, distributed generation, smart transmission, smart substation, smart distribution network, smart dispatching, EV charging and battery swapping, AMI, PFTTH， and smart community. All these efforts have effectively promoted the innovative development and practical application of the smart grid.

This Paper is a complete summary of China's research and development in smart grid. It is composed of five parts. (1) **China's philosophy of smart grid**: Adhering to both the "robustness" and "smartness" of the grid and emphasizing the coordinated development of the four phrases in the power grid, power generation, power transmission, power distribution and power consumption. In China, it means building an IT-based, automatic and interactive strong and smart grid backboned by ultra-high voltage (UHV) grids with coordinate grid development of various voltage levels. (2) **China's smart grid layout**: Based on the basic requirements of being strong & reliable, economical & efficient, clean & environmentally friendly, open & transparent and friendly & interactive, a smart grid development plan has been set up in six key segments of power generation, power transmission, power transformation, power distribution, power consumption and dispatching, and also in the communication and information platform. (3) **China's smart grid standardization**: establishing a smart grid collaborative innovation mechanism led by grid companies while involving research institutes, equipment manufacturers and consumers; drawing up 363 enterprise standards, 145 industrial standards, 66 national standards and 19 international standards on smart grid and UHV. (4) **Smart grid application in China**: constructing the world's largest wind and solar power storage and smart transmission demonstration project including 100MW wind power, 40MW solar power and 20MW energy storage; constructing two 1000kV UHV AC transmission projects and two ±800kV UHV DC transmission projects; constructing 656 smart substations covering 110 (66) kV to 750kV; developing and applying the smart grid dispatching technology support system covering power dispatching at national, provincial and prefecture levels, and the monitoring system for main power sources, major transmission lines and key equipments; forming the world's largest power consumption information collection system, EV charging and battery swapping network and smart power consumption platform with 170 million smart meters, 383 EV charging and battery swapping stations

and 17 thousand charging spots, providing PFTTH to 27 thousand households. (5) **Conclusion and outlook**: smart grid prospect and key directions of future development.

This Paper can serve as a valuable reference for international counterparts to get to know China's smart grid development. The author hopes to promote better and more extensive application of smart grid in the world by sharing the experiences and latest achievements of smart grid in China, as a move to address the increasing tension on global energy issues and to promote the sustainable development of human civilization.


## KEYWORDS

Smart Grid, Ultra High Voltage (UHV), Planning, Standard, Power Generation, Transmission, Consumption, Distribution, Dispatching, Power Fiber

## 1. Preface

Since the 1990s, with the rapid development of information, communication, sensing and electric power, smart grid technology has been gradually popularized. Faced with worldwide security pressure from power grid, energy and economy, this new century is nurturing and developing the third industrial revolution featured by IT technology and renewable energies. Accelerated development for smart grid is ushering in. **(1) Massive blackouts [1-2].** 140 widespread blackouts have occurred since 1965, causing huge economic and social losses. The large-scale August 14$^{th}$ Blackout in 2003 in America affected 50 million people and lost 61.8 GW of electricity, causing 1-billion-U.S.-dollar direct economic loss and 30-billion-U.S.-dollar indirect economic loss. The July 2012 India blackout that occurred on 30 and 31 July 2012 took 48GW of power offline, affecting 670 million people. Building a smart grid has become a major solution for utilities and experts to address grid security and prevent widespread blackouts. **(2) Energy and environmental conflicts [3]**. World energy shortage and environmental pollution have become ever more severe. New energies have to be developed and utilized to address the energy shortage. However, the intermittent and random features of wind and solar power pose higher requirements on the security and adaptability of the power grid. Smart grid thus becomes the key to promote new energy and realize a coordinated development of energy and environment. **(3) International financial crisis.** Since 2007, global financial crisis has plunged the world economy. The economic revitalization has become the core for current development, which requires new economic growth point. As a technology-intensive and capital-intensive industry, smart grid provides the solution for cracking down practical grid difficulties and energy problems. This strategic emerging industry can also boost the economic development and drive investment and employment. Therefore, the development of smart grid has become the common choice among various countries, energy industries and power companies.

As countries may differ in their economic development stages, energy resource endowments and electric technology levels, their philosophies and emphasis on smart grid development are different [4-5]. For example, the initial drivers for the U.S. to develop smart grid are to improve grid structure and enhance power grid security and stability, while Europe wants to develop new energies. The drivers for China are to upgrade grid technology, build robust grids, and improve the grids' capability to allocate resources optimally, as well as improve the grids' adaptability and meet the demands for large-scale integration and accommodation of various kinds of energies. Relatively speaking, China has more to ask from smart grid developments, hence facing more pressures and challenges. This paper will focus on China's philosophy, planning, standardization and application of smart grid.

## 2. China's Philosophy of Smart Grid

In 2012, China's average electricity consumption per capita was 3618KWh, 39% of that in OECD countries, showing a rigid increase in energy demands. It is estimated that by 2020, the average electricity consumption per capita will reach 5700 KWh in China and the national installed capacity will reach 2000GW, of which, there will be 1180GW of coal-fired power, 400GW of hydropower, 200GW of wind power, 50GW of PV power, and 68GW of nuclear power. East and Central China has huge energy demand but scarce primary energy supply. However, West and North China has rich new energy resources such as wind and solar power but limited consumption needs. This determines the need for China to adapt to new energy development and consumption diversity, taking on the path for optimal allocation of large capacity over long distances. To develop smart grid in China, it is necessary to take care of new energy integration and large-scale power distribution and accommodation, which involves all the sectors in power generation, transmission, distribution, and consumption.

In consideration of the above reasons, China initiated the proposal to build an IT-based, automatic and interactive strong and smart grid backboned by ultra-high voltage (UHV) grids with coordinate grid development of various voltage levels at the 2009 International Conference on UHV Transmission [4]. The Strong and Smart Grid integrates a "strong grid backbone" and "smart technologies", with the intelligentization of power generation, transmission, transformation, distribution, consumption and dispatching as well as the comprehensive integration of grid information flow, electricity flow and business flow. This Grid should have three features. **The first feature is the UHV backbone grids.** UHV grids, which can transmit power in large capacity over long distances with little line loss, guarantee optimal allocation of electricity in a large scope as the foundation for backbone grids in

China. The key is to construct a UHV hybrid network with good coordinated of UHV AC and DC grids. It is also the signature of a strong grid catered to China's realities. **The second feature is coordinated development of grids at various voltage levels.** The overall coordination in various sectors, from UHV to distribution network, from power sources to customers, is emphasized to ensure the successful integration of various power sources, long-distance transmission, favorable accommodation and efficient consumption. It is also a practical demand from the instantaneousness of power generation, transmission, distribution and consumption, as well as a demand of real-time balancing law. **The third feature is IT-based, automatic and interactive.** It includes the intensive integration of information regarding grid topology, power capacity, control, operation and management. All grids should be integrated with intensive control and coordination as well as high degree of self-control, self healing, and fault-recovery. Highly interactive function should also be realized between power generation, power grid, customers, resources and the environment.

## 3. China's Smart Grid Planning

Constructing the smart grid is a systematic project. Scientific planning is the premise for smooth interconnection and coordinated development of all sections of the power grid. Right now China's grid structure is still weak. Therefore the intelligentization and the construction of the grid network need to be simultaneously advanced. A unified power grid planning becomes quite important, which includes grid construction and smart technology application. It also enables thorough integration of smart grid construction with grid construction in China, laying a better foundation for grid transformation. Based on the basic requirements of being strong & reliable, economical & efficient, clean & environmentally friendly, open & transparent and friendly & interactive, a smart grid development plan has been set up covering six key segments of power generation, power transmission, power transformation, power distribution, power consumption and dispatching, and also in the communication and information platform. Its development goal and priority has also been marked down [4]. It's the world's first smart grid development plan covering all areas of power grid. According to the plan, China's smart grid development has three phases: Phase 1 (2009-2010), the planning period; Phase 2 (2011-2015) the full-fledge construction phase; Phase 3 (2016-2020) the completion and enhancement phase. Currently we are in Phase 2.

## 4. China's Smart Grid Standardization

Currently, many smart grid research institutes and equipment manufacturers are engaged in developing and applying various kinds of technologies and facilities. There is an urgent need to address the dis-unified standards, interfaces, and incompatibility. To solve these problems, China has established a smart grid collaborative innovation mechanism led by grid companies while involving research institutes, equipment manufacturers and consumers, covering technical researches, equipment development, test and inspection, engineering application and standardization. (1) Establishing the National Energy Research (Test) Centre for Smart Grid Technology to work on technologies of custom power, smart power transmission and transformation, flexible transmission, micro-grid, smart power consumption, power storage, energy efficiency evaluation, and information security. (2) Establishing the National Energy Research (Test) Centre for Solar Power and the National Energy R&D (Test) Centre for Large-scale Wind Power Integration, which have fully-fledged test capability for wind turbines and PV stations. (3) Promoting the establishment of 3 new IEC technical committees, namely, TC 115 - High Voltage Direct Current (HVDC) transmission for DC voltages above 100kV, PC 118 -Smart Grid User Interface, and SC 8A-Grid Integration of Large-capacity Renewable Energy (RE) Generation. With in-depth researches, a systematic technological standard for smart grid has been worked out, compiling 363 UHV& smart grid enterprise standards, 145 industrial standards, 66 national standards and 19 international standards.

## 5. Smart Grid Application in China

Since 2009, China has successfully put into operation a number of smart grid pilot and demonstration projects(Figure 1) in fields of new energy integration, distributed energy, smart transmission, smart substation, smart distribution network, smart dispatching, EV charging and battery swapping, AMI, PFTTH, smart building, etc.

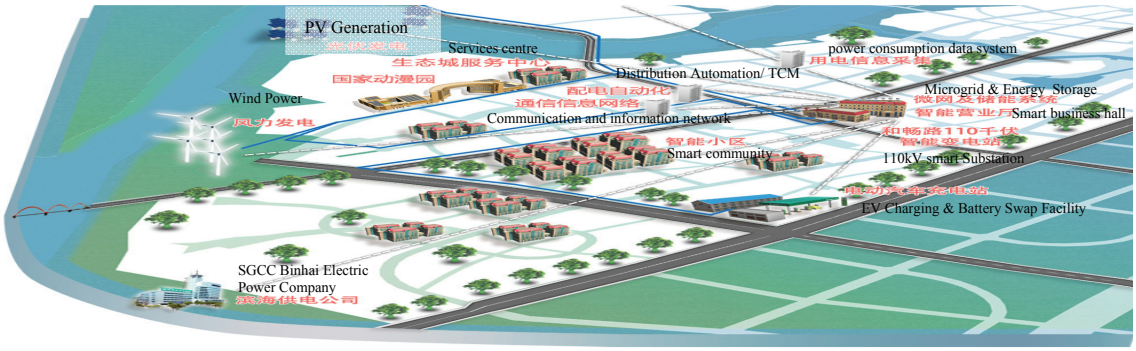


Figure 1 Sino-Singapore Tianjin Eco-city Smart Grid Comprehensive Demonstration Project

## 5.1 Power Generation

Facilitating new energy development is a key driver for smart grid construction. The focus is to solve the integration of intermittent and random wind and PV power generation and their accommodation. The company has embarked on a series of researches on large-scale wind power prediction and operation control, large-scale PV generation integration, co-ordination of conventional power plants, large-scale new energy cluster control, joint operation and control of wind, solar and hydro power, distributed power generation, micro-grid integration control, and power storage system application.

The National Wind/PV/Energy Storage and Smart Transmission Joint Demonstration Project (first phase) has been completed, which includes 100MW of wind power, 40MW of PV generation, and 20MW of energy storage. The project is world-leading in terms of its wind turbine model, adjustable PV installed capacity, varied chemical energy storages and joint operation technology of new energies. Combining wind power, PV power, power storage and power transmission, this project has significantly improved the capability of grid integration and new energy accommodation. Phase 2 of the project is currently under construction. Upon completion, its total capacity will reach 670MW. The application of these technologies has propelled the development of new energy in China. As of September 2013, the installed capacity of wind power within our service area reached 64GW, topping the world.

## 5.2 Transmission

Another driver of smart grid construction is to enhance grid transmission capacity and security. For China, the core is to address UHV grid construction and power transmission with large capacity and high efficiency over long distances, and improve real-time monitoring and live maintenance of transmission lines. Researches have been conducted regarding UHV AC/DC, VSC- HVDC, FACTS, large cross-section conductor, steel tower, disaster warning system, line status detection system, helicopter/ UAV smart inspection and high-altitude transmission. The idea of the UHV synchronous grid in North, East and Central China has also been verified [6-7].

We have completed 2 1000kV AC projects and 2 ±800kV DC projects. Another 1 AC and 2 DC UHV projects are under construction. These UHV projects have a total length of 10,000 km and a total transformation/inversion capacity of 100 GVA (Figure 2). Meanwhile, other transmission technologies have been developed, such as environmental-friendly engineering on transmission lines, on-line monitoring, helicopter patrol, on-site maintenance, anti-icing and windshield technology (Figure 3).


Figure 2 UHV projects in China

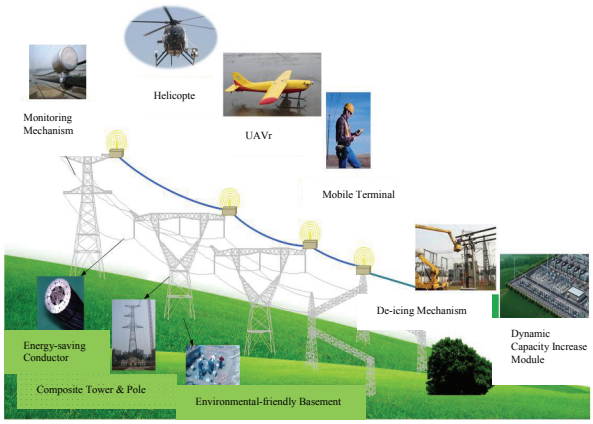


Figure 3 Main Equipments of Smart Transmission

### 5.3 Transformation

Substations occupy an important position in the power system. Smart substation is the key to bring the intelligentization of the whole system to the next level. The priority is to realize thorough station digitalization, equipment integration, business conglomeration, and compact design. (1) Thorough station digitalization is to digitalize all the signals, equipment, and control commands in the substation, form a digitalized substation mode, and establish a foundation for complete smart control and efficient management. (2) Equipment integration is to use novel technologies, materials and techniques to improve key equipment design like transformers and circuit breakers and integrate relevant sensors and smart components to enhance their function, control their size and improve reliability. (3) Business conglomeration is to incorporate protection control, automation and communication system to integrate on-line monitoring, on-site inspection, and maintenance, construct an all-in-one business system, reduce repetition and redundancy, realize coordinated control and improve the overall efficiency. (4) Compact design is to implement owner-oriented overall integrated design with reference to different voltage levels and different types of substations, optimize the layout of the main terminals and the stations, and minimize land occupation and investment.

To this end, researches have been launched regarding smart substation digital acquisition and control, device and system integration, equipment failure monitoring & self-diagnostic system, integrated business platform, and panoramic visual information system. As of Nov. 2013, 656 smart substations have been constructed covering 110 (66) kV to 750kV. In the principle of being highly integrated, rationally structured, advancedly equipped, cost-effective, energy-saving, environmental friendly, and integrated-regulation-supportive, the company has carried out researches and constructions on the next generation of smart substations. Right now six such stations have been built with little land occupation, low cost and high reliability. For example, a 220kV AIS smart substation occupies 40% less land with an investment on equipment lowered by 20% and a fault rate reduced by 32%. (Figure 4)

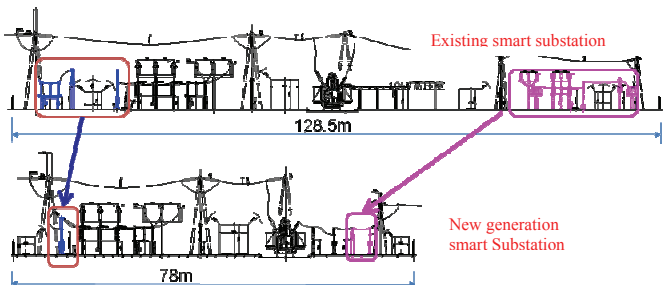


Figure 4 AIS type of Smart substation

### 5.4 Distribution

In recent years, with the popularization and application of distributed power, micro-grid, EV charging and discharging facilities, a great change is taking place to the structure and function of distribution grid, which is now supplying power with multi-directional interaction instead of the original one-way supply in the radiant mode. China plans to have 180GW distributed power in 2020, accounting for 11% of the total installed capacity. By then, electric vehicles will reach 5 million nationwide. The essence of smart distribution is to adapt to the integration of distributed generation and micro-grid and improve the adaptability of the distribution network. Relevant researches and pilot constructions have

been conducted in the field of distribution automation, smart community, urban energy storage device, self-healing control system, and repair management. Compared with the conventional one, the smart distribution grid is advantageous in information monitoring, automatic fault localization, rapid repair & power restoration, and friendly accommodation of clean energy.

### 5.5 Consumption

The key to smart power consumption is to satisfy various demands from customers and enhance interactivity. Therefore researches and applications have been rolled out on smart metering, power consumption data collection system, interactive marketing service, demand-side management, user-side distributed power, EV charging and battery swapping facilities, electricity bidirectional automatic billing, power quality monitoring and PFTTH, etc.

By now, we have established a power consumption data collection system deploying 170 million smart meters, realizing remote automatic meter reading, self-recharge, smart control, real-time consumption monitoring, line loss monitoring, and orderly consumption management, providing tariff management with the access of distributed generation.

383 EV charging and battery swapping stations have been built, equipped with 17 thousand charging spots. 2 inter-city service networks are taking shape around the Yangtze River Delta and the Bohai Bay, giving full support to various kinds of charging and battery swapping methods. Operation mode is being explored and practiced.

The electric power fiber combining the fiber and the power line has been developed and deployed in 27,000 households. While transmitting electricity, it can connect to the Internet, transmit telecommunication, radio and television signals, provide a variety of value-added services, innovate the grid operation mode, and offer richer, more convenient and more efficient services to the public.

### 5.6 Dispatching

Dispatching is the control hub of grid operation. Dispatching of modern large grid needs to be secure enough and back up the efficient utilization of clean energy and economical operation of the power system. In recent years, on the basis of unified national dispatching, China has constructed a new generation of smart grid dispatching technical support system at the national, provincial, and prefectural levels. With fully collected operation information, networked data transmission, online safety assessment, precise dispatch decision-making, automatic operation control, optimal grid-plant coordination, the large grid can maintain its good performance while achieving reliable operation, flexible coordination, high efficiency, low cost and environmental conservation.

Right now, the SCADA/EMS system that covers the dispatching above prefecture-level has been built, including the PMU (phasor measurement system) in the majority of 500kV (and above) power plants, large-scale wind power prediction system in most wind farms, abnormal climate monitoring system of most power transmission lines, and large-scale grid simulation system capable of real-time simulation. These systems enable us to fully grasp the grid's operational status, surrounding environment, development trend so that we can make good judgment based on the information and take corresponding measures to respond to emergencies in a timely manner. The joint operation of different types of power sources like wind, PV, hydro and thermal power can effectively utilize these energies. In 2012, electricity fueled by clean energy reached 29.2% of the total generation mix.

## 6. Conclusion and Outlook

### 6.1 Conclusion

China has made critical progress in smart grid planning, standardization and engineering application. Practices show that smart grid can provide solutions to new energy integration, electricity allocation in a large scope, and diversification of power consumption, and thus help promote safe, efficient and clean development of electric power industry.

### 6.2 Outlook

The 3rd industrial revolution featuring the internet technologies and renewable energies are fermenting and taking place around the world [8]. Both opportunities and challenges fall upon China in this new

round of revolution. It bears pragmatic significance for China to solve existing problems and promote the 3rd industrial revolution by taking advantages of its leading status in smart grid innovation and accelerating the construction of smart grid, also known as the "Energy Internet", backboned by strong power grids with the integration of modern grid technology, control technology and IT technology, and connecting large-scale energy bases, distributed generation and various customers. China attaches great importance to smart grid development. The focus for future researches and constructions will be UHV grid network, ±1100kV UHV DC transmission, new-generation smart substation for converter station, distributed power generation and micro-grid, demand-side management, energy storage technologies, smart city, and smart transmission lines.

## BIBLIOGRAPHY

[1] Xiaoxin Zhou, Jianchao Zhen, Guorong Shen, Yusheng Xue. "Lessons Learned from Massive Blackout in Northeast America" (Power System Technology, Sept 2003, pp 1-6).

[2] Günther B，Dusan P，Dietmar R，etc. "Lessons from Widespread Blackouts in the World" (China Power，Oct. 2007, pp 75-81)

[3] Zhenya Liu，"Electric power and energy in China"(Wiley, Apr. 2013, pp 1-43)

[4] Zhenya Liu，"Smart Grid Technology" (China Electric Power Press, Apr. 2010, pp 1-16)

[5] Massoud A.S., Wollenberg B F. "Towards Smart Grid" (IEEE power &Energy Magzine, Mar. 2005, pp 34-41)

[6] Zhenya Liu，"Ultra-high Voltage Grid"(China Economic Publishing House, Oct. 2005, pp 1-33)

[7] Zhenya Liu, "Innovation of UHVAC Transmission Technology in China"（Power System Technology, Mar. 2013, pp 1-8.)

[8] Jermy Rifkin，"The 3rd Industrial Revolution"（China Citic Press， Jun. 2012, pp 1-100）