National Quality Infrastructure Supports Smart Grid Construction in China - Taking the State Grid as an Example

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Abstract. The National Quality Infrastructure (NQI) plays an important role in technically supporting the construction of the smart grid. Taking the State Grid as an example, this paper analyzes the role of NQI in promoting and supporting UHV transmission projects, smart grid dispatching & control systems and new energy power generation in China. In the field of UHV transmission, the standard system supports the construction and industrial upgrading of UHV transmission projects, the testing system ensures the quality of engineering equipment, and the metering service ensures the accurate settlement of power generation, transmission and power supply. In the field of smart grid dispatching, NQI supports the successful research and development, all-round promotion and efficient operation of the D5000 System. In the field of new energy power generation, the technical standard system provides the basis for the grid-integrated system of new energy power generation. The improvement of testing capability has promoted the technological progress of the new energy industry. The certification of grid-integrated new energy has maintained the fairness and authority of the quality system.

1. Introduction
The concept of National Quality Infrastructure (NQI) was first put forward jointly by the United Nations Conference on Trade Development (UNCTAD) and the World Trade Organization (WTO) in 2005. In 2006, the United Nations Industrial Development Organization (UNIDO) and the International Standardization Organization (ISO) formally put forward the concept of National Quality Infrastructure, calling metrology, standardization and conformity assessment the three pillars of NQI. In 2007, the National Metrology Institute (PTB) and other institutions jointly published a research report: "The Answer to the Global Quality Challenge: a National Quality Infrastructure". According to the report, quality is the product of a series of related subjects through integrated, coordinated and interrelated behaviors, including metrology, standardization, testing, accreditation and certification [2]. In 2013, the World Bank released the "National Quality Infrastructure", which believed that the core elements of NQI include standards, metrology, testing, certification and accreditation, which were applied to all products and services to meet the needs of customers, manufacturers or regulators [3].

In 2010, smart grid was first mentioned in the work report of the Chinese government, and the "Guidance on Promoting the Development of Smart Grid" was launched in 2015. From then on, China's smart grid has seen rapid development. The smart grid proposed by China is a "unified and robust smart grid" with UHV power grid as the backbone network, featuring the coordinated development of power grids at all levels, and having characteristics of informatization, digitalization, automation and interaction [4]. It is the basic configuration platform [5] for the development of the Internet of energy. At present, green and clean energy is being used for power generation in China, which conforms to the global energy situation and is an important module for smart grid development.
[6]. State Grid Corporation of China (SGCC) is the world's largest public utility enterprise. In 2009, the SGCC put forward the strong smart grid development strategy, aiming at further improving the safety, reliability and economy of China's power grid operation, promoting the optimal allocation and efficient utilization of energy resources, and pushing energy conservation, emission reduction and clean and green development. Since 2010, the Strong Smart Grid enters full construction period; the construction of UHV grid and urban and rural power distribution network is advancing rapidly; the large-scale grid integration of new energy and distributed power sources is growing fast. Key technologies of smart grid operation control and interactive service system have achieved major breakthroughs and seen wide application. The power supply quality and reliability of the State Grid have been significantly improved. In 2015, within the operation regions of the State Grid Corporation of China, the number of power grid accidents was 0 for three consecutive years, the average power outage time of urban households was reduced from 8.234 hours/household to 2.891 hours/household, the qualified rate of urban comprehensive voltage increased from 99.498% to 99.999%, and the on-grid power consumption of new energy units increased from 49.2 billion kilowatt-hour to 172.1 billion kilowatt-hour [7]. The substantial improvement in the grid operation quality is closely related to the full implementation of scientific and technological innovation and excellent quality management and the strengthening of NQI by SGCC.

2. NQI Promotes Rapid Development of UHV Transmission Projects in China

As one of the major national infrastructure construction projects, UHV transmission project features large investment scale, long industrial chain and can provide strong driving force for the national economy, which has great social and economic benefits. At present, the SGCC has completed the "three-AC-and-four-DC" UHV transmission project.

2.1. Establish a standard system to support engineering construction and industrial upgrading

UHV AC 1000kV and DC ± 800 kV are currently the highest transmission voltage levels in the world. At the early stage of the UHV demonstration project, there were neither applicable standards to be directly followed, nor mature engineering experience to be used for reference, nor commercial UHV equipment to be chosen from. The project team was faced with great challenges. The SGCC, supported by its independent innovation technology, guaranteed by a perfect test and inspection system, and based on the engineering construction practice, has actively implemented the "integration of technical research and development, standard establishment and engineering application". It took 4 years to study and construct the first set of international UHV AC and UHV DC technical standard system. At the same time, the Company has strengthened the implementation and application of the standards in all aspects of the project. In terms of controlling project cost, improving construction quality and ensuring operation safety, the standards have played its role in standardizing, leading and supporting the project. The establishment and effective implementation of the standard system have also driven the leapfrog development of China's electrical manufacturing industry. The equipment manufacturing level has been comprehensively improved, and a historic breakthrough has been achieved in internationalization strategy. The SGCC successfully won the bid for Brazil's Belo Monte Hydropower UHV Transmission Project, and Shenyang TBEA successfully won a US $100 million purchase order from Power Grid Corp. of India.

At present, multiple technical achievements related to UHV standards have been adopted by world authoritative technical organizations such as the International Electrotechnical Commission (IEC), the International Council on Large Electric Systems (CIGRE) and the Institute of Electrical and Electronic Engineers (IEEE). UHV AC voltage has become an international standard voltage. The High Voltage Direct Current Technical Committee (TC115, with its secretariat located in the SGCC) and the UHVAC System Technical Committee (TC122, whose chairman is an expert from the SGCC) initiated by the State Grid Corporation of China were approved by the IEC, which have led the formulation of 15 international standards, promoted the realization of "Led by China" and "Made in China" in the field of power grid. In the field of UHV equipment, China has formed a standard system
including national standards and industrial standards. At the same time, the relevant association standards are gradually forming. National standards form a standard system corresponding to international standards. The corresponding system of national standards and international standards is shown in Table 1.

Table 1. The corresponding system of national standards and international standards

| IEC/TC Number | IEC/TC Name                                                                 | China's Corresponding Technical Committee | China's Corresponding Technical Organizations |
|---------------|------------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------|
| IEC/TC11      | Overhead lines                                                               | SAC/TC203 overhead lines                  | China Electric Power Research Institute     |
| IEC/TC42      | High-voltage and high-current test techniques                               | SAC/TC163/SC1 high voltage test technology | China Electric Power Research Institute     |
| IEC/TC77      | Electromagnetic compatibility                                               | SAC/TC246 electromagnetic compatibility    | China Electric Power Research Institute     |
| IEC/TC78      | Live working                                                                 | SAC/TC36 live working                     | China Electric Power Research Institute     |
| IEC/TC99      | System engineering and erection of electrical power installations in systems with nominal voltages above 1 kV a.c. and 1,5 kV d.c., particularly concerning safety aspects | SAC/TC226 high voltage electrical safety   | China Electric Power Research Institute     |
| IEC/TC115     | High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV | SAC/TC324 high voltage direct current transmission technology above 100kV | State Grid Corporation of China              |

2.2. Set up a testing system to ensure the quality of engineering equipment

As the first UHV transmission project in the world, China independently developed, designed and manufactured the UHV equipment. To ensure the quality of the equipment and the safe operation of the power grid, The SGCC has optimized the allocation of resources. Considering the actual situation of UHV engineering project, the Company has set up the UHVAC test base, UHVDC test base, UHV tower test base and 4300m high-altitude test base in Wuhan, Hubei, Changping, Beijing, Bazhou, Hebei and Yangbajing, Tibet respectively, forming the UHV testing system with the most complete functions, the strongest test capability and the highest technical level in the world. The Company has fully functional and world-class testing instruments and equipment, the largest million-volt artificial pollution laboratory, the high-voltage test hall with world advanced standard, China's first electromagnetic compatibility laboratory with the largest scale and the most complete functions in the power industry, and a power cable laboratory with the largest scale and capacity in the world, forming the testing capability for the complete set of UHV equipment and laying a solid foundation for the establishment of UHV technical standard system.

Relying on a scientific, fair and authoritative testing system, the localization of UHV equipment has been successfully promoted. Taking the 1000kV Southeast Shanxi-Nanyang-Jingmen UHV AC test demonstration project as an example, all the engineering equipment is supplied by domestic enterprises, and the comprehensive localization rate of the equipment is above 90%. Through engineering practice, Key manufacturing enterprises in China have mastered the core manufacturing
technology of UHV equipment, the independent innovation capability of these enterprises has been continuously enhanced, and the process quality level and safety and reliability of domestic equipment have been significantly improved. Among them, UHV equipment developed and produced by Chinese manufacturers such as TBEA and Pinggao Electric has occupied a large market share in India and other places.

2.3. **Innovate UHV metering services to realize the organic integration of standards, testing and metering.**

Electromagnetic current transformer (CT) and capacitive voltage transformer (CVT) are the main transformers used for gateway energy measurement in substations, which are important components for electric energy metering. The accuracy of these transformers plays a key role in trade settlement among power generation, transmission and power supply departments. Especially for HV gateways, its role is even more important. Just a comprehensive error of 1% will bring huge economic losses.

In the field of UHV metering, the SGCC has made independent innovations and a large number of technological breakthroughs. It has established the highest national standards for a number of verification/calibration/testing projects and successfully applied them to testing, ensuring the accuracy of CTs and CVTs. In the development of test equipment, it has developed the integrated, modular and brickling block high-current test system and a multifunctional measurement and control device. The current-load capacity can be flexibly configured according to the actual working conditions on site, thus ensuring the authenticity and reliability of the test data. In terms of test technology, the vehicle-carried test is adopted for CT error calibration, which not only improves the test efficiency, but also greatly reduces the influence of hoisting on the accuracy of equipment. With the innovative application of multi-power-source excitation technology, reactive power compensation technology and other technologies to calibrate the GIS pipeline CTs, test problems such as GIS ultra-long pipeline withstand voltage have been solved. Since the construction of the UHV demonstration project, all special handover and acceptance tests have been successfully completed, providing technical guarantee for the successful operation of the UHV project. It marks that China's UHV field test and calibration capabilities have reached the world's advanced level, realizing the organic integration of standards with testing and measurement.

3. **NQI supports full application of smart grid dispatching control System**

3.1. **General Framework of Multi-level Smart Power Grid Dispatching Control System**

For the purpose of integrated operations, the main and standby systems of the smart power grid dispatching control system (hereinafter referred to as D5000 system) of China are constructed to the same system framework and have the same functions. On the one hand, the unified foundation platform is used to realize the integrated operation of various applications and the interaction with the management information system within the dispatching system, for sake of coordinating the operation of various application functions between the main and standby systems, and synchronizing the maintenance with the data of the main and standby systems. On the other hand, the foundation platform is utilized to integrate the operations among the dispatching control systems at various levels, realize the source end maintenance and system sharing of the models, data and images, collect the data and exchange between the plant station and the dispatching control center, as well as between different dispatching control centers. The general framework of smart power grid dispatching control system for multi-level dispatching (taking three-level system as an example) is shown in Figure 1.
3.2. *NQI supports successful R&D of D5000 system*

Based on independent innovation, while making breakthroughs in the key technologies of D5000 system, the SGCC has carried out the construction of standard system. The basic key requirements of the system architecture and overall design defined by the standard system have played an important guiding role in the D5000 system pilot project.

According to the set of standards, SGCC successfully completed the system construction including 5 dispatching organization levels and 9 pilot units in less than one and a half years. A comprehensive inspection of the standard system had been done in the pilot project. According to the standard system and the actual situation of the power grid, the pilot units successfully completed various tasks such as system design, equipment procurement, engineering construction, acceptance and evaluation. In view of the problems found in the process of standard implementation, they have systematically improved the D5000 standard system and finally form a D5000 standard system that can be popularized and applied, covering 24 parts such as system architecture and overall requirements. This standard system is the first set of standards for smart grid dispatching and control systems in the world. It provides directly implementable technical guidelines for the popularization and construction of D5000 system and lays a solid foundation for high quality during popularization and construction. Two standards, including General Model Description Specification for Power Grid, have been successfully approved by IEC.

3.3. *NQI supports D5000 system for popularization*

During the period of D5000 system popularization and construction, 40-50 systems need to be constructed every year. To effectively ensure the construction quality of each system, SGCC has continuously strengthened the network access testing of relevant equipment and improved project...
acceptance management. On the one hand, SGCC has organized the scientific research personnel of the power system automation equipment quality inspection and testing centers to research and develop master station system for power grid dispatching, general computer hardware equipment, testing standards for dispatching data network equipment, plant and station automation systems and special equipment for power systems, strictly implemented the procedures and standards of product network access testing, providing strong technical support for the application of high-quality equipment and the construction of high-quality projects. On the other hand, it has specified acceptance requirements by formulation of systematic and practical project acceptance standards, and established corresponding scoring rules to carry out acceptance work, providing an effective method to identify quality gaps and improve quality for local system construction.

3.4. NQI supports efficient operation of D5000 system
After extensive application of D5000 system is realized, NQI will play a more significant role in ensuring the improvement of system operation quality and system function quality. The functional requirements emerged and solutions found during system operation are directly reported for standard system development and revision. The improvement and implementation of the standard has effectively promoted the advancement of relevant technologies, and enables all system functions to be standardized and improved.

The data acquisition, data transmission, safety protection, synchronous clock and other devices that are closely related to the quality of D5000 system operation are not only required to be tested and approved for network access, but also subject to regular testing to reduce operational risks caused by equipment quality problems. In addition, it's necessary to test some equipment that need unified functional configuration, interface standards, design requirements and other characteristics, so as to implement standardized design.

The inspection instruments and tools of each inspection center are required to be calibrated regularly by the State Grid Measurement Center on an annual basis, which ensures the accuracy of the measurement values to the maximum extent possible, effectively ensures the accuracy and reliability of the inspection data, and ensures the authenticity and credibility of the evaluation results of the equipment subject to examination. Relying on advanced testing capability, SGCC has established comprehensive experiment and verification platforms, such as smart grid dispatching and control system experiment and verification platform and substation simulation platform. It has developed comprehensive capability of power system simulation test, and can fully support the technical research, development and debugging, integration test, software evaluation and standard development of D5000 system, and support the efficient operation of D5000 system.

4. NQI promotes development and product upgrading of the new energy power generation industry
Since the implementation of the Renewable Energy Law in January 2006, China's new energy power generation such as wind power and photovoltaic power generation has developed rapidly, and has now become the country with the largest scale and fastest development of new energy grid integration in the world. Compared with conventional power sources, power generated by wind or PV has obvious intermittence and random fluctuations. Feeding large-capacity new energy sources into a power grid will affect the safe and stable operation of the power grid. To achieve coordinated development of new energy and power grid, SGCC has played a positive role in promoting the development and product upgrading of China's new energy power generation industry while ensuring the large-scale safe grid integration and efficient consumption of new energy in China by relying on independent innovation and through the construction of a new energy grid integration technical standard system, the establishment and improvement of inspection and testing capabilities, and the development of new energy grid integration certification.
4.1. Establish a technical standard system to provide basis for grid integration of new energy power

Based on the status quo of China's energy development and power grids, since 2005, SGCC has started the research and construction of a new energy grid integration technical standard system suitable for China's new energy development mode and power system characteristics. It has researched and formulated a technical standard system covering the planning and design of new energy such as wind power and photovoltaic, grid integration, test and inspection, and dispatching operation. In addition, it has issued 12 national standards, 23 industry standards and 24 enterprise standards, comprehensively guided large-capacity new energy power grid integration and operation in China, provided standard basis for equipment research and development, system design, testing and debugging, and production and operation of new energy power generation and grid integration, and effectively supported the rapid development of new energy in China [8]. SGCC initiated the establishment of IEC SC8A, namely the "Grid Integration of Large-capacity Renewable Energy Sources" Technical Sub-committee (which undertakes the work of the Secretariat). In October 2015, the international standard IEC TS 62910-2015 Low Voltage Ride-through Test Procedures for Grid Integration Photovoltaic Inverters initiated by SGCC was officially released. It is China's first international standard for grid integration of photovoltaic, successfully realizing the international promotion of China's experience and achievements.

4.2. Establish and improve the inspection and testing capability to lead the technological progress of the new energy industry

While standardizing the grid integration of new energy generated power, SGCC has increased its investment in scientific research and made breakthroughs in key technologies. Relying on the China Electric Power Research Institute, it has built the National Large-scale Wind Power Integration R&D (Test) Center (NWIC) and the National Solar Power Generation R&D (Test) Center. Both centers have passed the accreditation of the China National Accreditation Service for Conformity Assessment (CNAS) and the accreditation of the China Metrology Accreditation (CMA). By the end of September 2015, on-site low-voltage ride-through tests of 219 wind power models, low-voltage ride-through consistency assessment of 258 wind power models, and grid integration performance tests of 317 photovoltaic inverters were completed[9]. In 2013, the China Electric Power Research Institute was accepted as a member by the Measuring Network of Wind Energy Institutes (MEASNET). It has become the first MEASNET member that is not from Europe or America, marking that its testing capability has been recognized by international peers and reached the international advanced level.

Through grid integration testing, while ensuring safe operation of power grids, it provides a public research and development test platform for the industry to improve the technical level of integrating equipment with grids, lead the technological progress of the industry and serve the overall development of the industry. At present, it has supported more than 40 wind power/photovoltaic product manufacturers to carry out product function debugging and performance improvement. It has promoted the continuous improvement of China's new energy equipment manufacturing industry, and provided internship and training for operating enterprises, scientific research institutions, manufacturers and institutions of higher learning, and has provided a practice base for training high-level wind power/photovoltaic professionals and talents.

4.3. Carry out grid integration certification of new energy power generation and maintain the fairness and authority of the quality system

Certification is an evaluation method to check the implementation of measurement and standards. At present, a wind turbine type certification system, a wind power grid integration certification system and a photovoltaic power generation product certification system have been formed in the world.

In view of the fact that China has not yet carried out the certification for grid integration of new energy power and cannot evaluate the characteristics of the large-capacity integrated new energy power generation that has been put into operation, In April 2015, the Certification and Accreditation Administration of the People’s Republic of China officially approved China Electric Power Saipu
Certification Center (Beijing) Co., Ltd. to obtain the legal qualification certification, and the company has become the only third-party certification institution in China to implement certification for grid integration of new energy power generation. China Electric Power Saipu Certification Center can evaluate whether the overall grid integration performance of new energy power stations complies with the standards through document review, on-site inspection, modeling, simulation and testing on the premise that each equipment such as wind turbines and photovoltaic inverters meet the quality requirements. The certification results can provide a basis for power grid dispatching agencies to give priority to dispatching high-quality new energy, and the newly-built wind farms that have not been certified can improve the grid integration safety by implementing corrective measures. Through the establishment of the certification system, an all-round new energy grid integration management system has been formed in which testing and certification promote each other. It provides an institutional platform for China's new energy power stations to carry out grid integration performance evaluation, empowers the new energy industry to have greater independent innovation capability as well as healthy and stable development.

The quality infrastructure of new energy power generation has strongly supported the planning, design and operation of 84.97 million kilowatts of wind power and 23.21 million kilowatts of photovoltaic power. It is a strong guarantee to effectively convert the investment of 1 trillion RMB in new energy fixed assets into economic results and benefits of energy conservation and emission reduction, bringing direct and indirect economic benefits of more than 2.5 billion RMB[10].

5. Summary
When implementing the strategy of strengthening smart power grids, SGCC will further strengthen the national quality infrastructure, improve the inspection, testing, certification and accreditation mechanisms in equipment purchase, equipment operation, equipment maintenance and other aspects, and promote the effective implementation of smart grid standards and measurement standards. It will give energetic support to build relevant laboratories to provide a good test environment and support platform for standard development; strengthen the design of smart grid standard system, improve the standards in all aspects from design, construction, operation to acceptance, and promote to improve the implementation of measurement, inspection, certification and accreditation and strengthen the construction of measurement management system, improve the measurement service mechanism, and provide solid technical foundation for standard development, inspection and testing, certification and accreditation. Under the strong guarantee of continuously improving the NQI system and mechanism, it will commit itself to enabling smart grid-related equipment manufacturing, software manufacturing, engineering design, engineering management and conformity assessment services to maintain or gradually reach the international leading level. This will help to realize the idea that all countries in the world understand and accept UHV technology to promote the optimal allocation of energy resources, build a global energy network, promote the interconnection of global power grids, actively consume new energy power, ensure safe and reliable power supply, and deal with global energy problems.

Acknowledgments
This research was financially supported by the President Foundation of CNIS (582019Y-6776) and National Key Research and Development Program (2016YFF0204206).

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