Ultra-High Voltage AC/DC Grids

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Preface

More than a century since its inception, the world's power grid technology has seen rapid development, featuring higher voltage levels, more expansive interconnections, and stronger resource allocation capabilities. From the beginning of the 21st century, building a strong and smart grid—a modern grid system capable of allocating electricity across nations or even continents and flexible enough to adapt to renewable energy development and diverse needs—has become the direction and strategic choice for power grid development around the world. The construction of a strong and smart grid plays an essential role in promoting coordinated development of energy, economy, and environment.

1. **Security, efficiency, and cleanliness are important goals for energy development**

   Energy is a basic need to sustain economic and social development. The increasing global resource shortage and worsening climate change have imposed mounting constraints on energy development. How to take advantage of the new round of energy revolution to accelerate the strategic transformation of energy and maintain its secure, efficient, and clean supply is a common challenge faced by all.

   Energy is a multidimensional issue that involves policy, technology, market, and environment. To address it properly, energy has to be looked at with a "Grand Energy Vision." The development mode of energy needs to be transformed with a global vision, sustainable concept, strategic initiatives, and innovative technologies. Its development should be coordinated with that of the economy, society, and environment. Additionally, efforts are needed to promote the transitions of the following dimensions:

   - *Energy mix*: from high carbon to low carbon
   - *Energy utilization*: from extensive to intensive
   - *Energy allocation*: from local to global
   - *Energy service*: from unidirectional to intelligently interactive

   Eventually, a secure, efficient, and clean modern energy supply system should be achieved.

   Since the twenty-first century, the worldwide development and use of energy has been expanding, and renewable energies have been experiencing a continuous and rapid boom, presenting a significant trend of diversified energy mix. Electricity is a secure, quality, efficient, and clean secondary energy. Using electricity to replace the share of fossil fuels in end-use consumption of energy is already an obvious trend. The power grid is a basic means to transfer electricity, allocate resources, perform market transactions, and serve customers. To realize secure, efficient, and clean energy development, we must fully exploit the functions of the grid in transferring electricity and allocating resources, highlight the central role of electricity, and diversify the mix of primary energy sources. This is the only way to enable sustainable energy development. According to Jeremy Rifkin, author of *The Third Industrial Revolution*, Internet technology and renewable energy are booming to create a powerful "Third Industrial Revolution," which would have a profound influence on global development pattern. A strong and smart grid is a prerequisite for the third industrial revolution to be made possible. In recent years, the power grid has been recognized as a worldwide strategic focus for renewable energy development.

2. **Ultra-high-voltage grids are a well-justified means to realize a secure, efficient, and clean supply of energy**

Against this background, State Grid Corporation of China (SGCC), a backbone player in the energy sector, is facing strategic options and serious challenges regarding how to ensure electricity supply and how to maintain sound development of grids.

After carefully studying the nationwide demand on electricity and the geographical mismatch between resources and demand, SGCC proposed a "Grand Energy Vision" and a global perspective to promote technological innovations and concentrate efforts regarding transforming the development mode of energy and electricity. SGCC has launched a "One Ultra Four Large (1U4L)" strategy, which involves accelerating the construction of ultra-high-voltage (UHV) grids and promoting the intensive development of large coal power, large hydropower, large nuclear power, and large renewable power bases. The strategy focuses on "replacing coal and oil with electricity generated from remote sites" using electricity as a replacement to enable sustainability.

The construction of a strong and smart grid with the UHV network as its backbone is a fundamental solution to the underlying conflicts in developing energy and electricity, as well as a pressing task to meet the requirements of extensively developing large energy bases and renewables. The UHV grids will serve to deliver electricity from northwest China, northeast China, west Inner Mongolia, west Sichuan, Tibet, and some other countries to the load centers in east and middle China. As much as 76% of China's coal resources are located in the north and northwest regions, and 80% of water resources are located in southwest. The onshore wind energies are concentrated in northwest and northeast China, and in the north part of north China. However, more than 70% of China's energy demands come from the east and middle regions. With major coal explorations being shifted to the west and north, and with large-scale intensive exploitation of hydropower in the west, the development mode of electricity is being quickly transformed from local generation–demand balance to electricity supply by interconnected large grids. The increasing environmental pressure, high transportation costs, and land shortage have determined that east China is no longer an option for extensive deployment of coal-fired power plants, and that China has to find a strategy for its energy and electricity development, which features the transfer of massive electricity over long distances and optimization of allocating resources on a nationwide level. The transmission distance between large energy bases and load centers is usually 1000–3000 km, which is beyond the cost-effective transfer range of a traditional extra-high voltage system. Therefore, the electricity has to be transmitted in large capacity over long distances and consumed in a widespread region, and in an economic and efficient way. By connecting hydropower, wind power, and solar power to large grids featured by UHV grids, we can build a complementary energy allocation platform, boost the use of green and clean energies, and reduce carbon emissions. This is a practical and inevitable choice to build a beautiful China.

3. **Innovative practices and prospect of UHV grids**

   The development of a UHV transmission system has been incorporated into the outlines of the 11th and 12th Five-Year Plans, and the *Outline of the National Program for Long- and Medium-Term Scientific and Technological Development (2006–2020)*, making it an important component of the national energy development strategy.

   In January 2009, the Jindongnan–Nanyang–Jingmen 1000-kV UHV AC Pilot Project, which was independently developed, designed, and built by China, was completed and put into commercial operation. This UHV AC system has the world's highest voltage, largest capacity, and most advanced technologies. In July 2010, the Xiangjiaba–Shanghai ±800-kV UHV DC Pilot Project was completed and put into commercial operation. The commissioning of and stable operation of these UHV AC/UHV DC systems demonstrate the feasibility, safety, economy, and superiority of developing UHV transmission systems. Three years later, SGCC built two more UHV AC systems and two more UHV DC systems, which have been operating stably since they were commissioned.

   In April 2011, the UHV AC pilot project won the China Industry Award and was recognized by CIGRE as "a great technical accomplishment." In February 2013, the research program of "UHV AC Transmission Key Technology, Equipment and Engineering Application" won the Grand National Award for S&T Progress. China owns proprietary intellectual property rights of this technology, and it is the only country that has mastered it. According to the IEC, China's success in building the UHV AC system with the highest voltage level and largest transfer capacity in the world is "a major milestone in the history of the power industry," which establishes China's leading position in the world's UHV power transmission field.

   Accomplishments made in developing UHV grids are a combined result of the central government's foresight, support from various sectors of the society, and SGCC's efforts in independent innovation and hard work. China has achieved fruitful results in UHV grid development, including:

   - Four test bases (UHV AC, UHV DC, high-altitude, engineering mechanics) and two R&D centers (bulk power system simulation, DC system design) that form a full-fledged research and testing system for UHV and bulk grid, and master core technologies of UHV DC transmission and manufacturing capability of set equipment

- Accomplishing a multitude of world-leading innovations in UHV AC/DC transmission and transformation, control and protection of bulk power system, smart grid, and clean energy integration
- Formulating a series of technical standards for UHV and smart grid, involving 363 corporate standards, 145 industry standards, 66 national standards, and 19 international standards. China's UHV AC voltage has been accepted as the international standard voltage
- Acting as secretariats for four sub committees of the IEC, including High-Voltage Direct Current (HVDC) transmission for DC voltages higher than 100 kV, and Grid Integration of Large-Capacity Renewable Energy (RE) Generation

China's success in the UHV transmission field has presented new milestones in the world's grid technology developments and has initiated a new era of grids featuring UHV as the highest voltage. In the power grid community, China has become a creative leader after its historic transition from being a follower, realizing qualifying terms such as "Led by China" and "Created by China."

By 2020, the 12 east and middle provinces (municipalities) in the service area of SGCC will need 350 GW of electricity from other regions. The installed capacities of wind power and solar power will reach 200 and 50 GW, respectively. These increase the requirements of the capabilities of grids to transfer massive energy over long distances and to accommodate intermittent clean energy. As planned, SGCC will build five horizontal and five vertical UHV AC lines and 27 UHV DC projects, which will allow the allocation of 450 GW of electricity over a wide region and the delivery of 550 GW of clean energies. These systems will annually accommodate 1700 TWh of clean energies, which will replace 700 million tons of raw coal, reduce emissions of carbon dioxide by 1400 million tons, and reduce emissions of sulfur dioxide by 3.9 million tons.

With the wider use of UHV transmission and other advanced technologies, the grid is not only a carrier of electricity in the traditional sense but also a powerful platform for conversion, efficient allocation, and interaction of energies. Through this platform, primary energies such as coal, hydro, wind, solar, nuclear, biomass, and tidal are converted to electrical energy for complementary, coordinated, and rational use. The platform may connect large energy bases to load centers and realize long-distance, massive, and efficient transport of electricity, thereby optimizing energy allocation in a larger scope. It may also be integrated with Internet, the Internet of Things, and smart mobile terminals to meet the diverse needs of customers and serve the development of smart home, smart community, smart transportation, and smart city. The power grid will be an energy-based Internet platform in future China.

A comprehensive review of and wider use of our accomplishments in the UHV grid are significant. From the perspectives of power grid history, status quo, and trends, this book analyzes the driving forces behind the development of UHV grids, discusses the features of AC/DC transmission and the strengths of UHV systems, and proposes schemes for building UHV grids in China as well as the rationale for these schemes. This book describes the technical innovations and engineering practices in UHV transmission. It also summarizes experience with and technical standards for UHV practices. It is my intent, through the systemic descriptions given in this book, for the readers to get a general idea about China's UHV grid development. Comments and suggestions in this regard from more authorities and experts are welcome. This way, we will be better equipped to advance the power industry in a comprehensive, coordinated, and sustainable manner, to contribute to socioeconomic development, and to realize the Chinese dream of rejuvenating the nation.

Zhenya Liu

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Contents