Chapter 2
Development of UHV Power Transmission in China

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The objective requirements for the development of UHV transmission in China are raised based on the continued rapid growth in electricity demand, unevenly distributed energy resources, and lagged development of power grid. For long-distance and large-capacity power transmission, compared with the use of low-voltage level power transmission technology, UHV has obvious advantages in improving the transmission capacity, conservation of land resources, and reduction of transmission losses and savings of investment, etc. In addition, the development of UHV power transmission is of great significance for improving China's technological innovation ability and promoting the upgrading and development of the equipment manufacturing industry and other aspects.

This chapter first discusses the necessity of the development of UHV power transmission in China, and then the development planning and development process of UHV power grid in China, and finally provides a brief introduction of 1000 kV UHVAC and ±800 kV UHVDC projects that have been completed or under construction.

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2.1 Necessity in the Development of UHV Power Transmission in China

2.1.1 Objectively Required by the Sustained and Rapid Growth in Electricity Demands

Since the reform and opening up policy of China, with the sustained and rapid development of China's national economy, the electric power industry is under accelerating development. By the end of 2006, the national power generation capacity reached 620 million kW, and the total electricity consumption reached 2.8 trillion kWh. It is expected that the installed capacity will reach up to 1.3 billion kW in 2020, and the electricity consumption will reach 6.6 trillion kWh [1, 2]. The electricity demand and power construction scale are huge. Figure 2.1 shows the growth of China's installed capacity and electricity consumption since the reform and opening up (Figs. 2.2, 2.3; Table 2.1).

2.1.2 Objectively Required by the Long-Distance and Large-Capacity Power Transmission

China's basic national conditions are: the energies for power generation are mainly based on coal and water, and the energy resources and the development of productive forces were in reverse distribution. China is bound to develop long-distance and large-capacity power transmission due to these conditions, which are referred as of three "2/3" conditions hereafter [3].

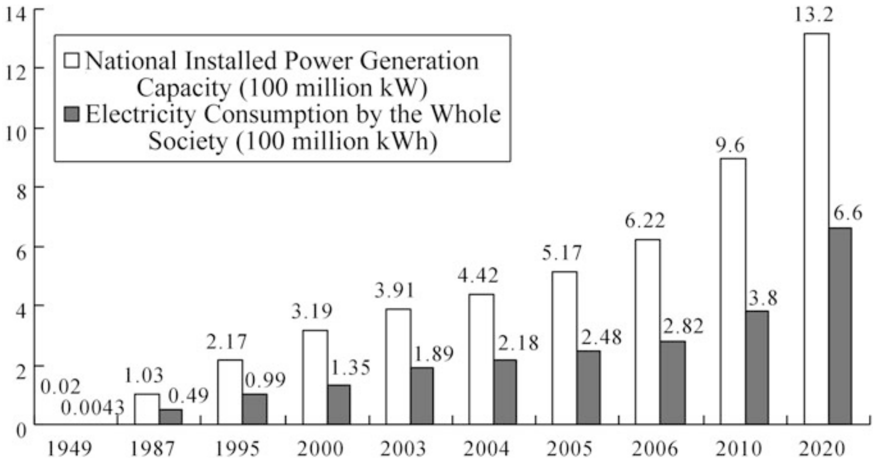

Fig. 2.1 Growth of China's installed power generation capacity and electricity consumption by the whole society

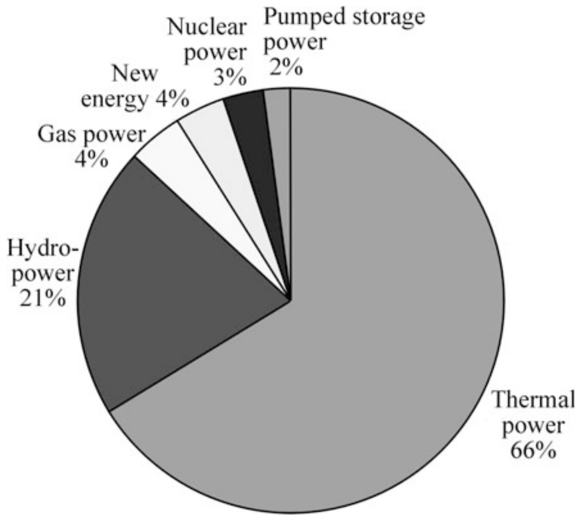

Fig. 2.2 Proportion of various power generation energies in China by 2020

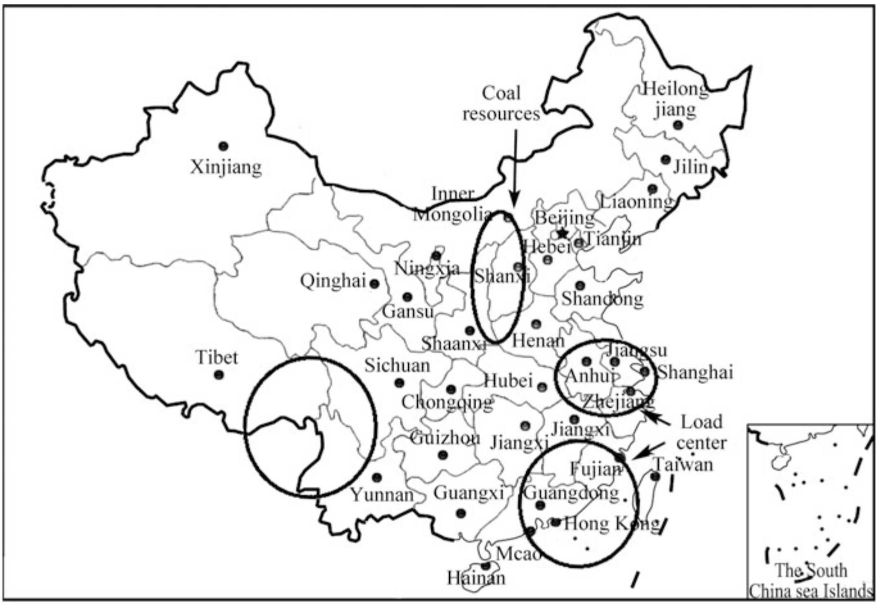

Fig. 2.3 Extremely uneven energy and load distribution in China

1. China's exploitable hydropower resources rank first in the world (about 395 million kW). By the end of 2008, the national total installed hydropower capacity (170 million kW) ranked first in the world, and the world's largest running hydropower station (Three Gorges Hydropower Station) by far is also in

Table 2.1 Distances from China's power bases to load centers

Starting point	Terminal point	Distance (km)
Northwest coal power base	Load centers in Central and East China	800–1700
Southwest hydropower base	Load centers in Central and East China	1500–2500
Xinjiang coal power base	Load center in East China	>3000

China. However, about 2/3 of the hydropower resources that can be developed are located in southwest of China, such as Sichuan, Yunnan, and Tibet Provinces, which are far from the load centers.

2. China's coal reserves are about 1 trillion tons, ranking the third in the world, but there are about 2/3 located in the "Three West Regions" of the northwest provinces (Shanxi, Shanxi, and western part of Inner Mongolia), which are far from the load centers.
3. About 2/3 of China's electricity load is located at the east coast and the economically developed areas to the east of Beijing–Guangzhou railway.

The distances between the above-mentioned energy resources and load centers are mostly between 800 and 3000 km. These basic conditions decide the necessity of using UHV power transmission in China, and the basic pattern of the power flow is necessarily large-capacity and long-distance power transmission, which is known as "West to East Power Transmission Project".

2.1.3 Objectively Required by the Basic Law of Power Grid Development

The development process of power systems from small scale to large scale, from low voltage to high voltage, from isolation system to interconnected system reflects the basic laws of power industry development. Using high-voltage level and developing large-scale power grid are the general trend of the development of the world's electricity. The construction of national grid with UHV power grid as the backbone and the coordinated development of power grid at all levels are in line with the basic national conditions of energy resources and economic development of reverse distribution, are in line with the overall deployment of the national energy saving, can change the lagging behind in development of Chinese grid, and are effective ways to achieve a coordinated development of the power grid and power sources, as well as the urgent need to build a resource-saving and environment-friendly society.

2.1.4 Required to Ensure Safe and Reliable Energy Transmission

The transportation of coal has a very high reliability under normal circumstances, but under specific conditions, this energy transmission is also affected by external factors, of which the most obvious one is the impact of the snow disaster weather. Due to the snow in winter weather coupled with the pressure of passenger transport during the Spring Festival in China, the rail and road freight transmission will be severely affected. A large number of coal-fired electricity generating units that far from coal producing areas are suffering from the shortage of adequate electricity coal supply, resulting in a wide range of power shortage phenomenon appearing in winter season in China, bringing inconvenience to people's lives, and posing the enormous threat to the safety of production. Although the safety of the power transmission has ever affected by the snow disaster, with improved transmission technology, the anti-ice capacity of grid will be growing, and the issue of melting ice will be considered as a key technical problem for the UHV transmission line at the beginning of the design, to ensure that the impact of disasters to the line is as small as possible, and to improve the safety and reliability of power supply. Therefore, locally converting the primary energy in the rich region into electricity, and having it efficiently delivered to the load-intensive areas by means of UHV lines, to achieve simultaneous development of power transmission and coal transportation, as well as coordinate with and complement each other, thus improving the reliability of energy supply, have become an important problem to be solved urgently in China.

2.2 Development Process of UHV Power Transmission in China

The research of UHV transmission technology in China started relatively late. Since 1986, the UHV power transmission research had successively been included in China's "Seventh Five-Year Plan", "Eighth Five-Year Plan", and "Tenth Five-Year Plan" key science and technology research programs. During 1990–1995, Significant Project Office of the State Council organized "argumentation on long-distance transmission mode and voltage levels"; during 1990–1999, the thematic studies on "UHV early demonstration" and "feasibility of million volts AC high voltage transmission" were organized by the Science and Technology Commission of China.

It is proven by the practical experience of the development of EHV and UHVAC and UHVDC transmission in different countries that, whenever it is necessary to adopt a new transmission of one higher voltage level, it generally must go through three stages: First, build a new experimental research base to conduct the test and research on the various basic characteristics of the transmission systems of the new voltage level and related equipment; second, construct an industrial test project; third, construct an official commercial transmission systems. In general, these three stages will take 10–20 years [4–6].

2.2.1 Preliminary Study of UHV

Since 1986, China Electric Power Research Institute, Wuhan High Voltage Research Institute, Electric Power Research Institute, and related universities have carried out the basic research on UHV power transmission, including the discharge characteristics of UHV external insulation, environmental impact of UHV, power frequency, and operating over-voltage, etc. In 1994, Wuhan High Voltage Research Institute constructed a test line section at 1000 kV voltage level, with length of 200 m, and 8 bundled conductors. At the tower experimental station constructed by Electric Power Research Institute in 2004, the prototype strength test can be carried out for the UHV single circuit, 8 × 800 mm bundled conductor, 30°–60° angle tower, and the shockproof design for power transmission lines can be tested. China Wuhan High Voltage Research Institute started the construction of UHV outdoor test site as early as in 1988. By 1996, China's first true class type 1000 kV UHV test line had been formally completed, and therefore, China had its first large-scale UHV test and research unit.

2.2.2 Construction of UHV Test Base

2.2.2.1 UHVAC Test Base of Wuhan High Voltage Research Institute

To fully meet the requirements of comprehensive study of UHVAC and UHVDC transmission technology and the electrified assessment of UHV power transmission equipment etc., the State Grid Corporation has constructed two new larger and more modern UHV research bases. The UHVAC test base was started in September 2006, and the double-circuit test line was fully charged in June 15, 2007; the UHVDC test base was started in March 2007, and the test line was fully charged in June 28, 2007. The construction of UHV test bases plays a role in optimizing the design of UHV construction by creating the conditions for providing empirical evidence and technical support, and it also tested the ability of Chinese design, manufacture, and construction of UHV projects to some extent.

The UHVAC test base is located in Wuhan City, including UHVAC single-circuit and double-circuit test lines on the same tower, electromagnetic environment measurement laboratory, environment and climate laboratory, charged assessment courses for UHV equipment, and other test equipment. The transmission line and towers at the base are as shown in Figs. 2.4 and 2.5.

The UHVAC test base covers an area of 133,400 m^2, and the equipment is developed and provided by more than 20 manufacturers in China. Its comprehensive testing capabilities create a number of world firsts, including:

1. adjustable geometry of UHV test lines and functions of tower optimization test;
2. having the devices to simulate the external insulating properties of the test conditions at altitude up to 5500 m;
3. all-weather electromagnetic environmental monitoring system;
4. pollution flashover testing capabilities of full-size UHVAC insulator string;
5. function of UHV GIS/AIS full-voltage and full-current live examination field;

Fig. 2.4 Single-circuit test lines

Fig. 2.5 Double-circuit test lines

6. voltage levels and capacity of power frequency resonance test device;
7. comprehensive training function and conditions of UHV operation, maintenance, and live working.

2.2.2.2 Beijing UHVDC Test Base of China Electric Power Research Institute

UHVDC test base is located in Beijing, consisting of the UHVDC test line section, outdoor test field, test hall, pollution and environmental test chambers, line electromagnetic environment simulation testing site, corona cage, insulators laboratory, and arresters test chamber. Experimental studies can be fully carried out to test UHVDC up to ±1000 kV electromagnetic environment, insulating properties, etc., and the charged assessment of the device for a long time. Currently, the line test in the base has successfully been boosted to ±1100 kV and started a stable operation, which can provide valuable design basis and strong technical support for the engineering design of new voltage level.

The transmission lines and towers in the UHVDC test base are as shown in Fig. 2.6.

Fig. 2.6 UHVDC test lines and towers

2.2.2.3 Yunnan Kunming High-Altitude UHV Test Base of China Southern Power Grid

China Southern Power Grid built a UHV test base in Kunming, Yunnan, with the study objects also are 1000 kV AC and ±800 kV DC, and the research focuses on the outer insulation at high altitudes.

2.2.2.4 High-Current Switching Test Base of Xi'an High Voltage Apparatus Research Institute

The test site has the ability to conduct 1100 kV/120 kA AC equipment capacity test, 1100 kV AC equipment insulation test, ±1100 kV DC converter valve insulation, and run tests, which have reached the world advanced level, and some of which are in the international leading level.

Whenever a new voltage level is used, many new problems will occur. Because the research at test base is often not sufficient, and if it is not assessed through the actual test run, the result may not be cautious and conservative enough, likely to cause serious damage. Therefore, it is an appropriate and prudent practice to build an industrial test project first to find problems, accumulate operating experience, and improve the mastering of new technologies. The undertaking of costly and unprecedented UHV power transmission project is even an essential step.

2.2.3 China's UHV Transmission Projects

Up to August 2017, six 1000 kV UHVAC power transmission lines and nine ±800 kV UHVDC power transmission lines have been built and put into operation. There is still another 1000 kV UHVAC power transmission line and the other four ±800 kV UHVDC power transmission lines will be put into operation at the end of 2017. Moreover, one ±1100 kV UHVDC power transmission line is being built and will be put into operation in 2018.

2.2.3.1 Southeast Shanxi–Nanyang–Jingmen 1000 kV UHVAC Transmission Demonstration Project

The project started from Shanxi Changzhi Substation (Jindongnan Substation), through Henan Nanyang Switchyard, and ended at Hubei Jingmen Substation, with total line length of approximately 640 km, rated transmission power of 5000 MW, and total static investment of 5.688 billion Yuan. The project was commenced in August 2006 and put into operation at the end of 2008. After the completion of 168-h trial run at 22:00 on January 6, 2009, it was officially put into commercial operation. The project scale covered: a bank of 3000 MVA transformers and a bank of 960 Mvar high-voltage shunt reactors installed at Jindongnan Substation; two banks of 720 Mvar high-voltage

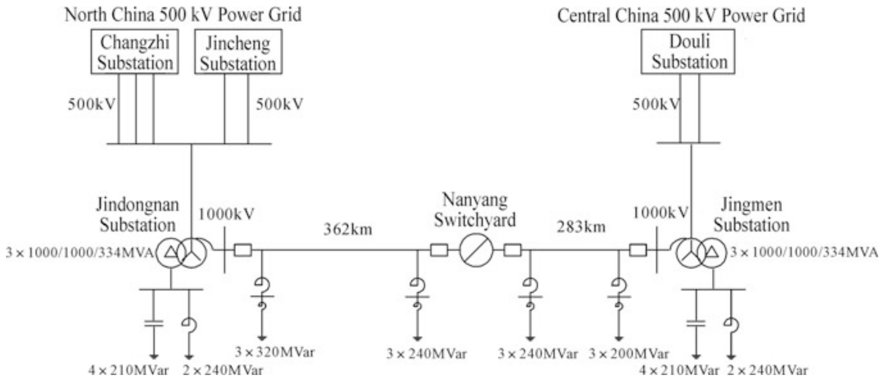

Fig. 2.7 Sketch of UHVAC project

shunt reactors installed at Nanyang Station which was a switchyard; and a bank of 3000 MVA transformers and a bank of 600 Mvar high-voltage shunt reactors installed at Jingmen Substation. All these three stations adopted the 3/2 circuit breaker wiring method, with incomplete strings applied at the initial stage of construction and two circuit breakers installed, as shown in Fig. 2.7.

The State Grid Corporation expanded the project in 2011, with a bank of 3000 MVA UHV transformers additionally installed at Jindongnan Substation and Jingmen Substation, respectively, and two banks of 3000 MVA UHV transformers additionally installed at Nanyang Switchyard. The supporting primary and secondary electrical equipments such as switches are installed ether. The UHV series compensators with 40% compensation degree (20% on each side) were installed in the line section from Southeastern Shanxi to Nanyang, and the UHV series compensators with 40% compensation degree [concentrated at Nanyang side] were installed in the line section from Nanyang to Jingmen. The UHV series compensators, large-capacity UHV switches, two-legged UHV transformers, and other new UHVAC devices were successfully used in this project, with integrated localization rate of over 90%.

The 1000 kV Southeast Shanxi–Nanyang–Jingmen UHVAC Demonstration Project Expansion Works was officially put into production on December 16, 2011. After the expansion, the three stations, i.e., Jindongnan Substation, Nanyang Switchyard, and Jingmen Substation, were installed with two banks of UHV main transformers with capacity of 3 million kW and the maximum transmission capacity up to 5 million kW.

2.2.3.2 Huainan–Shanghai 1000 kV UHVAC Transmission Project (Power Transmission Project from Anhui to Eastern China)

This project was commenced in October 2011 and completed in August 2013. The Power Transmission Project from Anhui to Eastern China started from Anhui 1000 kV Huainan Substation, through Anhui 1000 kV Wannan Substation and Zhejiang 1000 kV Zhebei Substation, and ended at Shanghai 1000 kV Huxi Substation, with transformation capacity of 21 million kVA, overall line length of 2 × 648.7 km, and total investment of about 18.6 billion Yuan. The system had a nominal voltage of 1000 kV and the maximum operating voltage of 1100 kV, using the large-capacity UHV transformer with rated capacity of 3 million kVA and the sulfur hexafluoride gas insulated metal enclosed switchgear with rated interrupting current of 63 kA, erected on the same tower in double circuits for the full line. This project was completely and independently designed, manufactured, and constructed by China.

The Power Transmission Project from Anhui to Eastern China, connecting the coal power bases in Anhui Huainan and Huaibei and the load centers of East China power grid, undertook the outward power transmission task of the coal bases in Anhui Huainan and Huaibei. After the project is completed, the scale of electricity transmission from Anhui to East China will be expanded and the safe and reliable outward power transmission from the coal power bases in Huainan and Huaibei will be ensured, and further to meet the electricity demand by north Zhejiang and Shanghai, having important economic and social significances.

2.2.3.3 Yunnan–Guangdong ±800 kV UHVDC Transmission Project

The Yunnan–Guangdong ±800 kV UHVDC Transmission Project is not only the independent UHVDC transmission demonstration project in China, but also the first UHVDC transmission project put into commercial operation in the world. This project started from Chuxiong Converter Station in Lufeng County, Chuxiong Prefecture, Yunnan Province in the west and went to Suidong Converter Station in Zengcheng District, Guangzhou City, Guangdong Province in the east, through Yunnan, Guangxi, and Guangdong provinces, with transmission distance of 1373 km and transmission power of 5000 MW. The project was put into monopolar operation on December 28, 2009 and put into bipolar operation on June 18, 2010. The total investment was about 13.2 billion Yuan.

2.2.3.4 Xiangjiaba–Shanghai ±800 kV UHVDC Power Transmission Demonstration Project

The Xiangjiaba–Shanghai ±800 kV UHVDC Demonstration Project was officially put into operation in July 2010. The project started from Sichuan Fulong Converter Station, through eight provinces and cities, i.e., Sichuan, Chongqing, Hunan, Hubei, Anhui, Zhejiang, Jiangsu, and Shanghai, and ended at Shanghai Fengxian Converter Station, with overall line length of approximate 1907 km.

The project had a rated current of 4000 A, rated transmission power of 6400 MW, and the maximum continuous transmission power of 7200 MW. The project adopted the main wiring method of double 12-pulse converters connected in series (400 + 400 kV) for each pole. The capacity of converter transformers was (24 + 4) × 297.1 (321.1) MVA (with four for standby); the type of converter transformer was the single-phase double-winding transformers fitted with on-load tap-changer; the ±800 kV DC switchyard adopted bipolar wiring and was provided with bypass circuit breaker and disconnector circuit for each 12-pulse valve bank; Fulong Converter Station had nine circuits of 500 kV AC outgoing lines, and Fengxian Converter Station had three circuits of 500 kV AC outgoing lines.

2.2.3.5 Jinping–Sunan ±800 kV UHVDC Transmission Project

This project started from Yulong Converter Station in Xichang City, Sichuan in the west, through eight provinces and cities, i.e., Sichuan, Yunnan, Chongqing, Hunan, Hubei, Anhui, Zhejiang, and Jiangsu, and ended at Tongli Converter Station in Suzhou City, Jiangsu Province, with overall line length of 2059 km and total investment of 22 billion Yuan. On December 12, 2012, the Jinping–Sunan ±800 kV UHVDC Power Transmission Project was officially put into commercial operation after the full completion of system commissioning and trail operation.

The project increased the UHVDC transmission capacity from 6400 to 7200 MW, and broke through 2000 km in the power transmission distance for the first time, creating a new record in UHVDC power transmission. After the project was fully put into operation, the electricity of about 36 billion kWh could be transmitted to East China annually.

2.2.3.6 Yunnan Puer–Guangdong Jiangmen ±800 kV DC Power Transmission Project (Nuozhadu DC Project)

This project started from Yunnan Puer Converter Station and ended at Guangdong Jiangmen Converter Station, with overall line length of 1413 km and rated transmission capacity of 5 million kW. On September 3, 2013, the Yunnan Puer–Guangdong Jiangmen ±800 kV DC Power Transmission Project began to send power to Guangdong, which was the second UHVDC transmission line constructed by China Southern Power Grid Company after the Yunnan–Guangdong ±800 kV UHVDC Transmission Project. Yunnan has abundant hydropower resource, with economic and exploitable capacity of 95.7 million kW in far future. By the later period of the "Twelfth Five-Year Plan", in addition to meeting its own electricity demand, there will be a lot of surplus hydropower for outward transmission. The completion and operation of this project are of important significance for optimizing the configuration of resources in East and West China, transmitting the clean power in West China and meeting the rapidly growing demand for electricity by Guangdong and other provinces.

2.2.3.7 Northern Zhejiang–Fuzhou 1000 kV UHVAC Transmission Project

The construction of the project was commenced on April 11, 2013, officially put into operation in December 2014. The Northern Zhejiang–Fuzhou UHVAC Transmission

Project starts from Zhejiang 1000 kV Zhebei Substation, goes through 1000 kV Zhezhong Substation and Zhenan Substation, and ends at Fujian 1000 kV Fuzhou Substation, with overall line length of 2 × 603 km, transformation capacity of 18 million kVA, and newly built lines of 2 × 603 km. The total investment is more than 18 billion Yuan. The Northern Zhejiang–Fuzhou UHVAC Transmission Project is an important part of the UHV main grid framework in East China, which has important significance for improving the transmission capacity of Zhejiang and Fujian networking, meeting the needs to send out the surplus electricity of Fujian power grid during the peak load period in near future and getting such benefits from the interconnection between the main power grids of Fujian and East China as peak load shifting and regulation, interbasin compensation, and surplus and deficiency regulation.

The Northern Zhejiang–Fuzhou UHV Transmission Project is the third UHVAC transmission project built in China after the Southeast Shanxi–Nanyang–Jingmen Project and the Huainan–North Zhejiang–Shanghai Project.

2.2.3.8 South Hami–Zhengzhou ±800 kV UHVDC Transmission Project

This project, with total line length of 2210 km and project investment of 23.39 billion Yuan, is the UHVDC transmission project with the highest voltage level, the largest transmission capacity, and the longest transmission distance in the current world, passing through six provinces, i.e., Xinjiang, Gansu, Ningxia, Shaanxi, Shanxi, and Henan, and ending at Zhongzhou Converter Station in Zhongmu County, Zhengzhou. The project, approved for construction commencement in May 2012, is the major measure to further promote the strategies of “Development of West China” and “Power Transmission from West to East”, promote conversion of Xinjiang resource advantages, serve the local economic and social development, and ease the contradiction between power supply and demand in Central China.

This project was formally put into operation in January 2014. It will provide annually more than 40 billion kWh of electricity to Henan, which is equivalent to the energy produced by more than 20 million tons of coal annually transmitted to Henan in a clean and efficient way. It can effectively alleviate the contradiction between the rapid growth of load and the inadequate total amount of resources and short supply of coal in Henan Province.

The six bundled conductors with large section of 1000 mm^2 were used in this project for the first time, and a number of innovation achievements in application of large-size angle steels and large-tonnage insulators were made.

2.2.3.9 Xiluodu–West Zhejiang ±800 kV UHVDC Transmission Project

The Xiluodu–West Zhejiang project was formally approved in July 2012 and put into operation in July 2014. The project started from Shuanglong Converter Station in Yibin, Sichuan, goes through 48 cities in five provinces, i.e., Sichuan, Guizhou, Hunan, Jiangxi, Zhejiang, and ended at Zhexi Converter Station in Jinhua, Zhejiang, with overall line length of 1728 km and transmission capacity of 8 million kW, which is the renewable energy key project during the "Twelfth Five-Year Plan" in China.

This project is significant to ensure the power outward transmission of the Sichuan hydropower and relieve power utility pressure in Zhejiang, which is beneficial to optimizing allocation of clean energy in a larger scope, has great importance to achieving balanced regional economic development, and is the embodiment of implementing the western development strategy and converting the western resource advantage into the economic advantage, a strategy move to implement the scientific concept of development in electric power industry and the concrete measure of State Grid Corporation to implement the strategic planning of UHV power grid with four huge resources and take the road of sustainable development.

Some of the UHVAC and UHVDC transmission projects that have been built or under construction in China are shown in Tables 2.2 and 2.3.

Table 2.2 UHVAC transmission projects in China

S/N	Project Name	Time Put into Operation	Rated Voltage /kV	Length /km	Transmission Capacity /MW
1	South Shanxi-Nanyang-Jingmen	2009	1000	640	5000
2	Huainan-North Zhejiang-Shanghai	2013	1000	2×648.7	6500
3	North Zhejiang-Fuzhou	2014	1000	2×603	4000–6000
4	Ximeng-Shandong	2016	1000	2×730	6500
5	Huainan-Nanjing-Shanghai	2016	1000	2×759	6500
6	West Inner Mongolia-South Tianjin	2016	1000	2×608	6500
7	Yuheng-Weifang	under construction	1000	2×1048.5	6500

Table 2.3 UHVDC transmission projects in China

S/N	Project Name	Time Put into Operation	Rated Power /MW	DC Voltage /kV	Length /km
1	Chuxiong-Guangzhou	2010	5000	±800	1373
2	Xiangjiaba-Shanghai	2010	6400	±800	1907
3	Jinping-Sunan	2012	7200	±800	2059
4	Nuozadu-Guangdong	2013	5000	±800	1413
5	South Hami-Zhengzhou	2014	8000	±800	2192
6	Xiluodu-West Zhejiang	2014	7500	±800	1653
7	East Ningxia-Zhejiang	2016	8000	±800	1720
8	Jiuquan-Hunan	2017	8000	±800	2383
9	Shanxi-Jiangsu	2017	8000	±800	1119
10	Ximeng-Jiangsu	under construction	10000	±800	1620
11	Shanghai-Shandong	under construction	10000	±800	1238
12	Northwest Yunnan-Guangdong	under construction	5000	±800	1959
13	Jarud-Qingzhou	under construction	10000	±800	1234
14	Zhundong-South Anhui	under construction	12000	±1100	3324

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