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An overview of power transmission systems in China

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ABSTRACT

In the past 20 years, China's economy has grown rapidly, but so has the country's power industry. This paper provides a comprehensive introduction on the current status and the future development of the power transmission systems and grids, which include HVAC and HVDC transmissions, regional power grids and grid interconnections, several important operational issues, e.g., stability problems that China's power grids face, new technologies for increasing transmission capacity, and stabilizing the grids, and so on. Under the constructed UHVAC and UHVDC, some pilot projects and planned future development of UHVAC and UHVDC transmission systems are also introduced.

1. Introduction

China's electric power industry was started at the end of the 19th century [1]. Since 1949, the time when the People's Republic of China was established, this industry has been growing very fast. By the end of the 20th century, the total generating capacity of China's power industry was already placed second in the world. AC/DC transmission systems with 500 kV, 330 kV, and 220 kV AC lines, and ±500 kV DC lines were formed. There were 6 regional grids and 3 independent provincial grids in the main land of China. After the year 2000, with the rapid development of the national economy, China's power industry went into a new developing period. The development of interconnection of regional grids accelerated, and the goal of forming a nationwide power gird was preliminary achieved in 2005. At the same time, according to the distribution of resources and loads, China put forward its "Power Transmission from the West to the East" plan and then carried it out step-by-step. As a part of the plan, China will develop new 1000 kV UHVAC and ±800 kV UHVDC transmission system in order to significantly increase the transfer capability under three important transmission corridors, i.e., the north, mid, and south. These corridors can transfer sufficient power from the hydro and coal fired power plants in the West to the East where economic development is much more advanced. In the next 10–20 years, China will strengthen the interconnection of large regional grids. Four synchronous grids interconnected by HVDC are being planned to be established nationwide by the year 2020.

The rapid development of China's power grids creates opportunities but also presents challenges for the operation and control of the grids. Some operation security problems like the transient stability, the voltage stability, and the low frequency oscillation have to be resolved, too. At the same time, for rapid load increase and environmental protection, the transmission capacity of the corridors must be increased. To overcome these challenges, Chinese researchers have already started to develop new technologies, including flexible AC transmission system (FACTS) technologies, the compact line, operation and control technologies of HVAC/HVDC hybrid system, and so on. In the foreseeable future, these technologies will be widely applied to China's power grids to help ensure the security of the grids.

2. Overview of the development of China's power industry and power transmission systems

In 1882, the origin of the Shanghai Electrical Company symbolized the beginning of China's power industry [1–6]. By the end of 1949, the total installed capacity was 1.85 GW. After 1949, China's power industry developed much faster. The annual total installed capacity increased by 10%. In the two years, 1987 and 1995, the total capacity exceeded 100 GW and 200 GW, respectively. In 1996, the total capacity reached to stand at the second place in the world. Since 2000, China's GDP has increased 10%

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annually; correspondingly, the country's power industry entered into a new prosperous period. The total installed capacity reached 300 GW in April 2000, 400 GW in May 2004, and 500 GW in December 2005. The power generation of 2005 was 2414 TWh, at a 13.3% increase of the previous year. In 2006, the installed capacity exceeded 622 GW. It is estimated that the development of China's power industry will keep growing in the next 10–20 years. By 2020, the total installed capacity is expected to exceed 1500 GW.

China's power grid has passed through several periods. Before 1949, it developed very slowly, with a small scale. By the end of 1949, the total length of 20 kV or above transmission lines was 6475 km; the total capacity of all transformer substations was 3460 MVA.

After 1949, the construction of China's power grid accelerated, and the standard for voltage level of transmission lines was established, too. In 1954, the first 220 kV power transmission project, the Song Dong Li project in the northeast region of China was completed, thus, transferring power from the Fengman hydro plant to Liaoning province which is the base of China's heavy industry. In 1955, the first 110 kV power transmission project, Beijing Dongbeijiao to Guanting project, was completed with transmission lines stretching 105.9 km. In 1972, the first 330 kV power transmission project, the Liu Tian Guan project, was completed. It started from the Liujiaxia hydro plant to the Tangyu substation in Mei County, Guanzhong, Shanxi province via the Qin'an substation in Tianshui, Gansu province. The length of the transmission lines is 534 km. This project established China's Northwest Grid across several provinces. In 1981, the first 500 kV power transmission project, Ping Wu project, was completed. The length of the transmission line is 594.8 km, which starts from the Yaomeng power plant in Pingdingshan, Henan province to the Fenghuangshan substation in Wuchang, via the Shuanghe substation in Hubei province. Later, 500 kV backbone grids were formed gradually in the four regional grids including several provincial grids, i.e., the Central China Gird, the Northeast China Grid, the North China Grid, and the East China Grid. A 330 kV backbone grid was formed in the Northwest China Grid. In 1989, the ±500 kV HVDC project from Gezhouba to Shanghai was completed; the length of the transmission lines is 1052 km, and the rated capacity is 1200 MW. This project interconnected two regional grids in China for the first time. In September 2005, the first 750 kV power transmission project started, which demonstrated the great progress made in China's power transmission technology. In the next 10–20 years, China will continuously fund the construction of ultra high voltage grids, and a nationwide grid with a backbone grid of 1000 kV AC lines and ±800 kV DC lines.

With the drastic increase in the total length of transmission lines and higher voltage levels, China's big regional grids are being interconnected gradually. At the end of 1980s, the completion of the ±500 kV Gezhouba to Shanghai HVDC project established the trans-regional interconnection. In 2001, the North China Power Grid and the Northeast China Power Grid were interconnected. It was the first time that two big regional grids were interconnected via an AC line in China. In October 2001, a 500 kV AC line interconnected the East China Power Grid and Fujian Power Grid. In May 2002, the project to transmit power from Sichuan province to Central China was completed, interconnecting the Chuanyu Power Grid and the Central China Power Grid. On May 5th, 2003, the ±500 kV DC line with a rated capacity of 3000 MW from the Three Gorges to Changzhou was put in to use. This line had the highest transmission capability in the world at that time, transferring power from the Three Gorges hydro plant to East China. In September 2003, the Central China Power Grid and the North China Power Grid were interconnected, and thereby an inter-regional AC synchronized grid including the Northeast China Power Grid, the North China Power Grid, the Central China Power Grid including (the Chuanyu Power Grid) was formed. In 2004, this inter-regional gird was interconnected with the South China Power Grid by a DC line from the Three Gorges to the Guangdong province. In July 2005, a back-to-back DC project interconnected the Northwest China Power Grid and the Central China Power Grid, completing the nationwide grid interconnection. Later, with the completion of the Three Gorge hydro plant and the Three Gorge transmission system, a large AC and DC transmission system including the Central China Power Grid and the East China Power Grid was formed. The forecasted total installed capacity is more than 200 GW. In the future, with the completion of the north, middle, and south corridors in the "Power Transmission from West to East" plan, there will be a nationwide interconnected grid including the north, middle, and east interconnected grids in China.

3. HVAC (EHVAC and UHVAC) transmission systems

At present, transmission lines in China's power transmission system can be categorized into four voltage levels, i.e. 220 kV, 330 kV, 500 kV, and 750 kV [1–6]. The 330 kV and 500 kV transmission lines make up the backbone grids. At the end of 2005, there were 540 500 kV lines with a total length of 63,790 km and 204 500 kV substations with total transformer capacity of 282,100 MVA in major power grids. There were 154 330 kV lines with total length of 12,842 km and 60 330 kV substations with total transformer capacity of 25.21 GVA in the Northwest China. In the 1980s, the Ministry of Electric Power launched a study about higher voltage level. According to the study, 750 kV and 1000 kV are specified as the standard voltage levels, and they are one level higher than 330 kV and 500 kV, respectively. On September 26, 2006, the first 750 kV AC line in China from Guanting to Lanzhou was put in use. In August 2006, China's first 1000 kV AC pilot project, from Changzhi, Shanxi province via Nanyang, Henan province to Jinmeng, Hubei province, reached the stage of implementation. The two lines and some other lines that will be constructed in future will constitute China's future backbone grids.

3.1. *The 330 kV AC transmission system' in the Northwest China Power Grid*

For historical reasons, the Northwest China Power Grid is the only large regional power grid which adopts 330 kV lines to make up its backbone grid in China. In June 1972, the first 330 kV transmission project, the Liu Tian Guan project from Liujiaxia to Guanzhong via Tianshui, was completed and put into operation. Later, for delivering the power generated by the Hancheng power plant outward, another 330 kV line from Hancheng to Tongchuan via Zhuangtou was built. In 1985, a 330 kV line from the Qingling Power Pant to the Wuyuan substation in Sanmenxia, Henan province.was completed, and another 330 kV line from Jingyuan in Gansu province to Qingtongxia in Ningxia Hui Autonomous Region was completed. In October 1987, for transmitting the outward power generated by the Longyangxia hydro plant in the Qinghai province, two 330 kV lines named Long Hua and Long Hai were built. In 1990, the Daba Power Plant in Ningxia Hui Autonomous Region was put in use, and several 330 kV lines were built to connect it to the grid. Up to then, a 330 kV trans-provincial interconnected power grid was formed. Now, the northwest China 330 kV power grid extends from Wulan, Qinghai province and Jiayuguan, Gansu province in the west, to Hancheng, Shanxi province and the Qingling power plant in the east, to Qingtongxia, Ningxia Hui Autonomous Region and Yuling, Shanxi province in the north, and to Hanzhong and Ankang in Shanxi province in the south, along with three 330 kV lines between Shanxi and Gansu province, six 330 kV