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The Xiangjiaba-Shanghai 800kV UHVDC project Status and special aspects

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SUMMARY

This paper presents the current status of the 800 kV UHVDC technology and presents how the experience and confidence gained at an 800 kV long term test station is being utilized in executing the 800 kV UHVDC long distance bulk power transmission Xiangjiaba - Shanghai.

As a first step in the R&D activity, a long term test circuit installation was built in order to provide final qualification for the newly developed 800 kV products and for boosting confidence in 800 kV HVDC technology. It was energized at 855 kV DC in November 2006 at STRI, Sweden.

The experience gained during the test circuit operation was utilized during the realization of the equipment. The critical equipment, like converter transformers, wall bushings and thyristor valves have all successfully passed their type tests and installation is almost complete. The converter stations passed Open Line test at 800kV DC in December 2009.

A number of 800 kV HVDC projects have entered the execution stage in China. At the same time, many other 800 kV DC projects are under planning by several utilities in other parts of the world, like in India and Africa.

KEYWORDS

800 kV DC, HVDC, Bulk power transmission, UHVDC, UHV transmission.

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1. INTRODUCTION

In countries with major growing economies like China and India, the increasing demand for energy is in conflict with the requirements for reducing the environmental impact from energy production. So far, the only large scale renewable energy production is done by utilizing hydro power, with plants that are usually located far from the consumer centers.
UHV offers the promise to meet the challenge to deliver large quantities of electricity from remote power generating stations to urban centers to meet the increasingly intense demand of electricity. UHV is needed to deliver electricity to cities with a minimum number of transmission lines. In growing industrial and population centers where demand is on the rise, but room for transmission lines is limited, this is further critical because only few power line corridors are available.
800 kV Ultra High Voltage Direct Current (UHVDC) transmissions are economically attractive for bulk power transmissions, say above 5000 – 7000 MW, over long distances, like 1000 – 2500 km [1]. The following transmission projects at UHVDC are already in the execution phase: A) The project object of this paper: Xiangjiaba – Shanghai ±800 kV HVDC Transmission (XS800), rated for 6400 MW, to transmit power over a distance of 1935 km, owned by State Grid Corporation of China (SGCC), and B) Yunnan – Guangdong ±800 kV HVDC Transmission (YUG800), owned by China Southern Power Grid, rated for 5000 MW to transmit power over a distance of 1418 km. For its part Power Grid Corporation of India Ltd. is driving its NER/ER – NR/WR Interconnector I ±800 kV Multi-terminal HVDC Transmission (NEA800) project rated for 6000 MW to transmit power over a distance of around 1728 km to feed power into Agra and New Delhi area. The project is in the bidding phase. So is the Jingping – Sunan ±800 kV HVDC Transmission (JPS800) project, which is rated for 7200 MW to transmit power over a distance of 1935 km, owned by State Grid Corporation of China. This will be the largest transmission system in the world. There are several other 800 kV HVDC transmission projects around the world in advanced stages of planning.

2. EQUIPMENT DEVELOPMENT

In order to define the relevant requirements on the equipment, a working group for UHVDC was initiated by SGCC, called the Common Engineering Platform, with frequent meetings between future user and potential equipment suppliers. The important outcome from this working group was requirements on the system and critical equipment that were both needed by the end user and feasible for the manufacturers.
In order to meet the demands for such large projects, ABB started an R&D programme early in 2005, well in advance, with the goal to develop and test the equipment and system tools needed for 800 kV UHVDC. In order to define the proper requirements for the equipment to be developed, the results achieved in the Common Engineering Platform served as an important input.
The equipment R&D work focused on equipment connected to the pole voltage, with special attention to converter transformers, bushings and external insulation [2, 3]. The reasons for this become apparent in view of the principles exposed below. The most significant difference between equipment for HVDC compared with equipment for HVAC is the need for proper DC grading. The R&D on the system side focused on the advantages and disadvantages of the different possible configurations and modularization, with special attention to their impact on the reliability and availability of the transmission, but also with attention to their impact on the stresses imposed on the equipment.
When applicable, HVDC equipment is built up by modules where each module is provided with a proper resistive voltage grading resistor as well as an AC/transient grading capacitor. With a proper voltage grading, the voltage stress in each of the modules will be the same, regardless of if the module is part of an 800 kV apparatus or of a 500 kV apparatus. For some insulation systems the situation is more complicated, since it is normally not possible to arrange the DC grading with physical resistors: the DC grading must be secured by other measures.
For outdoor equipment exposed to pollution and rain/fog, the coordination between the internal and external voltage grading is also an important issue. Poor coordination can result in damage of the insulators due to radial voltage stress.
In AC, the field distribution is determined by the dielectric permittivity (ε) of the insulation materials, while in DC the steady state field distribution is controlled by the resistivity (ρ) of the insulation

materials. In real service operation, equipment is exposed to both DC and transients of varying frequency. When switching on the voltage, an AC-like voltage distribution occurs, and after a certain time (typically three "overall time constants" of the insulation system, $\tau = \rho * \varepsilon$), the DC-like field distribution is obtained. Due to the complex nature of the insulation system, the geometry and position of the different parts, the transition "AC to DC" may occur very differently in different locations inside and outside the bushing.
The resistivity of the insulation materials of, for example, a bushing is of course very high; besides, it is heavily temperature dependent. As a result, the typical overall time constant can vary by several orders of magnitude and can be very long. In fact, hours, days, or weeks are quite typical. It is therefore important to verify the electric field distribution also in its "natural" environment, e.g., at valve hall temperatures of up to 40-50 °C. Thus a long term test using a 'heated valve hall' was considered to simulate the real time stresses.
The phenomena described above, are more complicated at higher DC voltage and larger volume of the insulating media, such as for 800 kV. Thus, not just designing or making prototype or testing these 800 kV equipments, ABB installed them in an energized test circuit to obtain first hand, long term 800 kV operational experience [4, 5]. This was done to obtain confidence in the new technology as well as to gain time to resolve any unforeseen problem that might be revealed, and to verify the dimensioning of various parameters. In ordinary conditions, newly developed equipment is qualified by a series of type tests. As most of the dielectric type tests are short duration tests, supported by operational experiences of earlier products at similar voltage level, such qualification is considered sufficient. However, as for equipment for 800 kV HVDC there is no existing experience at this voltage level to verify the design, it was considered of importance to examine the equipment in a relatively long time span.

3. THE XIANGJIABA – SHANGHAI ±800 KV HVDC TRANSMISSION PROJECT

The first stage of the Jinsha River Development Project is located in the area of Sichuan province and is larger than the well known Three Gorges project. It includes several hydro power stations in the Jinsha river valley. The dam construction began in 2005. The total number of generators will be 26 and the generation capacity will reach 18 600MW. The first generator is scheduled to be commissioned by the year 2012 and the completion of the whole project is scheduled for 2017.

The 6 400 MW Xiangjiaba – Shanghai ±800 kV DC Transmission Project is a bipolar transmission having one converter station in Fulong in the Sichuan Province and the other in Fengxian within the city of Shanghai. The Fulong rectifier converter station is located approximately 8 km from the site of Xiangjiaba hydro dam. As shown in Figure 1, Fulong will be connected to Xiangjiaba power stations by four 12-15 km long 500 kV AC lines. Fengxian will be connected to the AC system by three 4 km long 500 kV AC lines to the station Nanhui, which is part of the 500 kV AC ring around Shanghai city.

4. DESIGN FEATURES

A simplified single line diagram of Xiangjiaba – Shanghai HVDC Project is shown in Figure 2. The air core smoothing reactors are split up between the pole and neutral in the ratio of 50/50 %. This gives advantages for the insulation levels for the converter bridge, and has become a standard for similar converter stations. The bipolar system is rated for a continuous power of 6 400 MW (±800 kV DC, 4 000 A) at the DC terminals of the rectifier converter station. The transmission is designed to transmit full rated power up to the specified maximum ambient temperature without any redundant cooling in service. With redundant cooling in service, a continuous overload of 105% and 2-hour overload of 113% of rated power are achievable. With lower ambient temperature, the overload can be even higher i.e. for an ambient of 20?C, a continuous overload of 115% and 2-hour overload of 131% of rated power are achievable.
In order to give maximum reliability for the transmission system, the two poles can be operated completely independently. The only common equipment is in the neutral area.

The converters can be operated in a "de-icing mode" when higher current is wanted in order to melt ice deposited on the pole lines. In this mode two 12-pulse converters in each station are connected in parallel and operated at 400 kV, and depending on the conditions, the line current can be increased up to 7-8 kA.

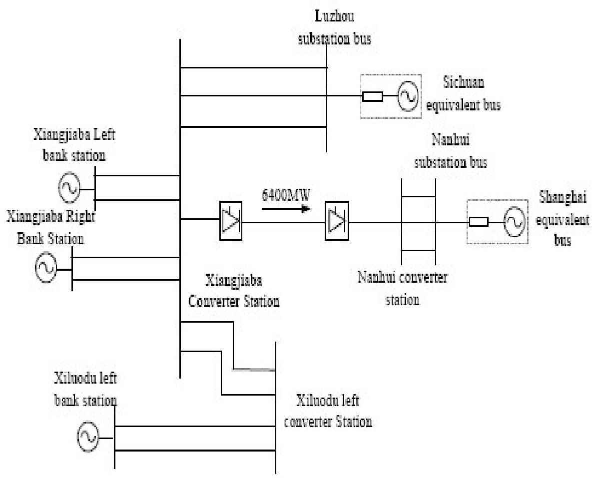

Figure 1. Power system

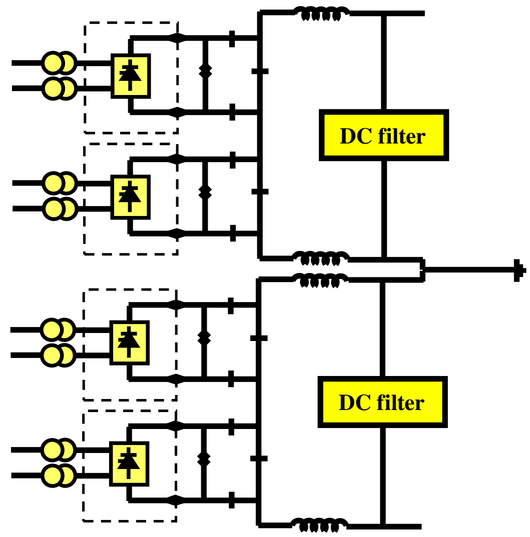

Figure. 2. Single line diagram

5. MAIN EQUIPMENT AND MAJOR TECHNICAL FEATURES

Manufacturing and erection of equipment is nearing its end. Pole 1 has already successfully performed Open Line Test at 800kV, just before Christmas 2009. The next milestone is to have Pole 2 in operation in June 2011.

5A. Thyristor Valves

For the converter bridges, air insulated, water cooled thyristor valves, arranged in double-valve configuration are suspended from the ceiling of the valve hall. Each single valve consists of 56 thyristors of type YST130 (6") in Fengxian. These thyristors have been specifically developed for high current applications. This is the first UHVDC project utilizing 6" thyristors. The thyristor valves successfully passed the dielectric tests for multiple valves and for single valve with the following characteristics:

1. DC withstand test, dry and wet with corona measurement
2. AC withstand test with corona measurement
3. Switching impulse test, dry and wet at 425 kV
4. Lightning impulse test at 420 kV
5. Steep front impulse test at 471 kV
6. Non-periodic firing test
7. Operational tests.

5B. Converter transformers

In the XS800 project, single-phase, two-winding converter transformers are used. Some of the transformers were manufactured in China and some in Sweden. Cooler banks are mounted on the tank itself, even though in Fengxian station an audible noise mitigation arrangement has been adopted.

Both wye and delta valve winding bushings protrude inside the valve halls. Main data of Fengxian converter transformer is as given in Table 1 below.

	Y/y	Y/d
Rated Power [MVA]	297.1	297.1
Rated Voltage [kV]		
- Line winding	515	515
- Valve winding	$157.6/\sqrt{3}$	157.6
Leakage Reactance [%]	16.8	16.8
Tap Changer Range [Steps]	+22, -6	+22, -6
- Step Size [%]	1.25	1.25
Insulation Levels [kV]		
- Line side LIWL	1550	1550
- Valve side LIWL	1800	1550
- Valve side SIWL	1600	1300
- Valve side applied AC	902	685
- Valve side DC withstand	1246	940
- Valve side DC polarity reversal	966	711

Table 1. Transformer data

The converter transformers for Fengxian, including those for the high voltage 12-pulse group successfully passed all the routine and type tests, with a partial discharge level during applied AC tests well below 100 pC, indicating proper design of the insulating system.

5C. Smoothing reactor

The smoothing reactors are of air insulated type; two units are installed per pole on the high voltage side [800 kVdc] and two units are installed per pole on the neutral voltage side. The main data for each of the smoothing reactors is as given in Table 2.

	Fulong/Fengxian
Nominal Incremental Inductance [mH]	75
Rated Current [Adc]	4000
Insulation Level [kV]	
- LIWL, terminal to ground	NA
- LIWL, terminal to terminal	1175

Table 2. Smoothing reactor data

5D. Wall bushings

The 800 kV wall bushings have successfully passed all the type tests with dielectric data as below:

1. Lightning impulse test at 1900 kV
2. Chopped wave impulse at 2185 kV
3. Switching impulse test at 1700 kV
4. AC withstand test at 905 kV
5. DC polarity reversal test at 979 kV
6. DC withstand test, Wet/dry at 1030/1238 kV

6. LATEST PROGRESS

The installation and commissioning have progressed at very good pace, and the line was energized in Open Line Test mode already just before Christmas 2009. The open line test consists of energizing the line to its rated voltage without transmitting power on the line, thereby checking all high voltage insulation integrity of the station and the line.

Figure 3. 400 kV dc valve hall

Figure 4. 800 kV dc valve hall

Figure *5. Converter transformers*

Figure 6. 800 kV dc filter

Figure 7. 800 kV dc smoothing reactors.

7. CONCLUSIONS

800 kV UHVDC is economically attractive for bulk power transmission over long distances. With the satisfactory progress of R&D efforts, converter equipment for 800 kV UHVDC is fully qualified and projects are being executed by three utilities.

A long term test installation was energized in November 2006, and its satisfactory performance, without any problems, has provided confidence in ABB's design for 800 kV HVDC equipments including design of corona shield arrangements and bus-bars.

At present, December 2009, the construction work of the converter stations for the XS800 project is almost finished, the critical equipment has been successfully manufactured, tested, installed and energized in order to meet the contractual commissioning dates.

With the confidence gained with satisfactory operation of the long term test circuit and the results from the manufacturing of equipment for the XS800 project, the conclusion is that 800 kV DC is ready to account for a significant part of world growth in power transmission capacity over the next several years.

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