BENEFITS OF SIMILAR HVDC BIPOLES FROM THREE GORGES POWER GENERATION COMPLEX

R. DASS*, A. KUMAR, G. FLISBERG, L. ENGLUND, M. LAGERKVIST
ABB Power Technologies AB
Power Systems HVDC
(Sweden)

LI WENYI, SUN JIAJUN, SHU YUNBIAO
State Power Corporation of China
(P.R. China)

The Three Gorges Hydroelectric Power Plant, currently under construction on the middle reaches of the Yangtze River, will be the largest of its kind in the world. It will comprise 26 generating units, each with a rated power of 700 MW. When all these units are commissioned in 2009, the total generating capacity of the plant will be 18.2 GW [1] [2].

The development of a matching evacuation system has been an equally challenging task. The evacuation system had to be such that it caters to the consumers located in the central as well as far southern and eastern parts of China by taking into account the long as well as short-term requirements of the connected grids. Besides fulfilling the technical requirements, the evacuation system needs to be economical in terms of initial investment as well as life-long operation and maintenance costs. This entailed that there should be a proper mix of AC and DC systems.

The planned evacuation system, which takes into the above aspects, consists of over 10000 km of HVAC and HVDC lines. The HVDC systems emanating from the Three Gorges power plant area, in first phase, include two bipolar systems namely; “Three Gorges - Changzhou ±500 kV DC Transmission (3GC)” [3] and “Three Gorges - Guangdong ±500 kV DC Transmission (3GG)”.

Keywords: Three Gorges – HVDC- Bipole – Operation – Maintenance – MACH2 – SCADA

1. SALIENT FEATURES OF HVDC BIPOLES

1.1. Geographical location

The two converter stations associated with Three Gorges - Changzhou ±500 kV DC Transmission Project (3GC) are at Longquan (Hubei province) and Zhengping (in Changzhou, Jiangsu province), about 890 km apart. Longquan converter station is situated some 50 km from the Three Gorges Dam. The receiving station at Zhengping is situated approximately 200 km from Shanghai. Power will be transmitted eastward during the peak generation period and toward the central power grid whenever reservoir water needs to be conserved.

* rebati.dass@se.abb.com
The converter station at the transmitting end of the Three Gorges - Guangdong ±500 kV DC Transmission (3GG) project is located 16 km from Jingzhou city, about 135 km from the Three Gorges power plant. The receiving station is at Huizhou, in Guangdong province. Power will be transmitted over a distance of 940 km.

1.2. Technical features

Both 3GC and 3G projects are bipolar transmission schemes with identical main primary and secondary equipment and operating strategies.

1.2.1. Power Rating

The links are designed for a normal rating of 2 x 1500 MW under the (relatively conservative) specified conditions. They have been designed for continuous as well as short time overload capabilities.

To minimize bipole outage, the HVDC system can be operated with balanced bipolar currents, using the ground mats of the converter stations as temporary grounding, should the ground electrodes or their lines be out of service.

The nominal reverse power transfer capability is 90% of the rated power. The HVDC links are designed to operate continuously down to 70% of the rated DC voltage. The salient main-circuit technical data are given in the Table I.

Table I: Salient main-circuit technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>3GC</th>
<th>3GG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal power rating, MW</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>Nominal dc voltage, kV</td>
<td>±500</td>
<td>±500</td>
</tr>
<tr>
<td>Transmission distance, km</td>
<td>890</td>
<td>940</td>
</tr>
<tr>
<td>Power overloads at max ambient temperatures with redundant cooling in service, MW:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td>3150</td>
<td>3150</td>
</tr>
<tr>
<td>2 hour</td>
<td>3390</td>
<td>3390</td>
</tr>
<tr>
<td>10 seconds</td>
<td>4230</td>
<td>4230</td>
</tr>
<tr>
<td>5 seconds</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td>Converter Transformers:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type Power rating, MVA</td>
<td>1-phase, 2-winding 297.5/283.7 (LQ/ZP)</td>
<td>1-phase, 2-winding 297.5/283.7 (JZ/HZ)</td>
</tr>
<tr>
<td>Smoothing reactors:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type Value, mH</td>
<td>Oil insulated 290/270 (LQ/ZP)</td>
<td>Oil insulated 290</td>
</tr>
<tr>
<td>Thyristor type</td>
<td>YST-90</td>
<td>YST-90</td>
</tr>
<tr>
<td>DC filter type</td>
<td>Passive</td>
<td>Passive</td>
</tr>
<tr>
<td>AC filter type</td>
<td>Passive</td>
<td>Passive</td>
</tr>
<tr>
<td>AC system voltage, kV</td>
<td>525/500 (LQ/ZP)</td>
<td>525/500 (JZ/HZ)</td>
</tr>
<tr>
<td>AC system frequency, Hz</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

LQ – Longquan, ZP – Zhengping, JZ – Jingzhou, HZ – Huizhou

1.2.2. Power circuit arrangement

The main circuit arrangement (Figure 1 and Figure 2) of the two links is identical except for the reactive power compensation equipment. Stable steady state and dynamic operation of the AC-DC systems is ensured by optimized use of the reactive power capacity of the generators in the Three Gorges power plant and the AC networks at each end of the links. One-and-a-half breaker configurations are used on the AC side at both stations.
In addition to the bipolar transmission scheme, the links can be connected for monopolar transmission with either a ground or metallic return. The main circuit connection on the DC side is typical for an HVDC bipole with overhead transmission line. Metallic return transfer breakers and ground return transfer switches have been installed to meet the requirements of monopolar metallic return operation, and provide capability for uninterrupted transfer. Neutral bus grounding switches are also installed at the neutral buses of both stations to meet temporary grounding requirements.

Figure 1: Main circuit arrangement for 3GC

1.2.3. **AC filtering**

Four types of filter are used: double tuned 11th and 13th, double tuned 24th and 36th, double tuned 12th and 24th, and C-type 3rd harmonic. Shunt capacitor banks, with and without damping reactors, balance the reactive power requirement at Jingzhou, Zhengping and Huizhou converter stations.

1.2.4. **DC filtering**

Robust passive DC filtering ensures a performance level of 500 mA_p (bi-pole)/1000 mA_p (monopole) for both projects. Each terminal pole has two filter arms designed as double tuned filters, one tuned to the 12th and 24th harmonics and the other to the 12th and 36th harmonics.
1.2.5. Control and protection

The projects’ control and protection strategies are realized with state-of-the-art MACH2™ (Modular Advance Control for HVDC) system. MACH2™ features high-level performance, low maintenance, a very powerful programming environment and good integration with SCADA systems. The SCADA systems enable information about the operating status of each converter station to be accessed remotely by dispatch centers. These centers have full remote control capability and can regulate power transmission on the link. Terminal-to-terminal communication is via optical fiber ground wire. Capacity not needed for communication is used for dispatch and for data transfer on the networks, but could also be used for commercial purposes.

Control functions such as power ramping, security & stability control, and frequency control are also integrated. The station engineer can adjust the interface and parameters as required by the system.

1.2.6. Thyristor valves

A double valve scheme (Figure 3) was chosen to take account of the converter transformers being single-phase, two-winding units. Longquan and Jingzhou converter stations have 90 thyristors (3 kA, 7.2 kV) per valve, while at the receiving stations Zhengping and Huizhou each valve has 84 thyristors (3 kA, 7.2 kV). Dry-type damping capacitors and film DC resistors are used. Comprehensive fire detection and protection is incorporated in the valve hall design.

Figure 3: Valve Hall at Longquan  Figure 4: Converter Transformer during testing

1.2.7. Converter transformers and smoothing reactors

The single-phase, two-winding converter transformers in the Longquan (Figure 4) and Jingzhou stations are rated 297.5 MVA, $525/\sqrt{3}:210.4/\sqrt{3}$ (210.4 for Y-D) kV, 16 % reactance, with an OLTC tap range of $+25/-5$ (1.25 % per step). The Zhengping transformers are rated 283.7 MVA, $500/\sqrt{3}:200.4/\sqrt{3}$ (200.4 for Y-D) kV, 16 % reactance. Here, the OLTC tap range is $+26/-2$. In the Huizhou station the transformers are rated 283.7 MVA, $525/\sqrt{3}:200.6/\sqrt{3}$ (200.6 for Y-D) kV, 16.8 % reactance, also with an OLTC tap range of $+28/-4$ (1.193 % per step). Dry-type bushings are used for the valve hall penetration. The converter transformers at Longquan, Jingzhou and Huizhou are also equipped with electronic control, allowing analysis and reporting, plus intelligent fan control to minimize losses.
The smoothing reactors are connected to the valves via the bushing penetrating the valve hall wall. An electronic control system for the reactors at Longquan, Jingzhou and Huizhou features the same capability as that provided for the transformers.

1.2.8. DC-side breakers and switches

SF₆ breakers are used for all the high-speed DC switches: metallic return transfer breakers, neutral bus grounding switches, neutral bus switches and ground return transfer switches. The ground return transfer switch is the only one of these to be of conventional passive design. All the others have an active auxiliary transfer circuit consisting of a capacitor and a charger. The charger gives the DC switches extra current commutation capability, enabling them to handle even the highest overload currents [4].

1.2.9. Operating configurations

The links can be operated in many different configurations and modes. Emergency operation is provided for, as is operation without telecommunication. Through accurate measurement and control, it is ensured that in the case of bipolar balanced operation with local station ground the unbalance current to ground will be zero.

The operating modes are:
- Bipolar
- Monopolar earth return and metallic return
- Reduced DC voltage (from 500 kV to 350 kV)
- Reverse power operation
- Bipole and pole power control
- Pole synchronous and emergency (separate) power control
- Pole backup synchronous control
- Pole current control

1.3. Distinct features

Since the Zhengping converter station is exposed to very heavy industrial pollution, the DC pole insulators had to be longer than those the manufacturers could provide. This and the difficulty of coordinating the external and internal insulation of extra-long bushings led to the decision to build indoor DC switchyards. All high-potential DC equipment is installed indoors and all the DC neutral equipment is outdoors. There are four separate halls for each pole: one for switches, two for the DC filter capacitor banks, and one for the DC PLC capacitor bank.

To keep the AC yard at Jingzhou converter station of 3GG as small as possible, outdoor SF₆ gas-insulated switchgear (GIS) is used for all of the ten 500 kV bays.

1.4. Commencement of commercial operation

The 3GC bipolar system is in commercial operation since mid 2003 and the 3GG bipolar system is planned to be in commercial operation in July 2004.

2. BENEFITS OF HAVING SIMILAR BIPOLES

Depending on the transmission distance, power to be transmitted, physical & electrical proximity of the converter stations, size of the connected AC networks and requirement on commissioning schedule of the HVDC links, the choice of similar HVDC bipoles could result into several techno-economic benefits. Most of these factors were favorable in driving the choice of the similar bipolar systems for 3GC and 3GG projects. The benefits start accruing
right from the planning stage - so was the case with these two projects. Some of the accrued as well as foreseen benefits are discussed in the sub-sections below.

2.1. Ease in evacuation system planning

A large amount of the power generated from the Three Gorges generation complex was to be transported to the bulk load centers in the far eastern and southern provinces of the country. It became easier and natural to go for the highest rating HVDC bipole for which well-proven equipment are available from the leading suppliers of the HVDC equipment. For subsequent stages of evacuation, it was a matter of adding more such links together with AC transmission reinforcements.

2.2. Short delivery time

There are a number of distinct stages in the execution of an HVDC project that determine the delivery time. These are as follows:

- Preliminary engineering – selection and preparation of sites
- Detailed engineering – design studies, station layouts, civil design and preparation of equipment specifications
- Selection of civil contractors
- Execution of civil works
- Selection of equipment suppliers
- Design of equipment by suppliers
- Manufacturing of equipment
- Preparation of transport logistics and selection of transporters
- Delivery of building material and equipment to the sites
- Selection of installation/erection contractors
- Installation/erection of equipment
- Testing and commissioning

Table II: Periods of completion of different stages of 3GG project

<table>
<thead>
<tr>
<th>Stage</th>
<th>Completion (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation of sites</td>
<td>2</td>
</tr>
<tr>
<td>Detailed engineering – primary equipment design and equipment specifications</td>
<td>4</td>
</tr>
<tr>
<td>Selection of primary equipment suppliers</td>
<td>5</td>
</tr>
<tr>
<td>Detailed engineering – station layout, civil and mechanical design</td>
<td>6</td>
</tr>
<tr>
<td>Detailed engineering – secondary equipment design</td>
<td>6</td>
</tr>
<tr>
<td>Design of equipment by suppliers</td>
<td>7</td>
</tr>
<tr>
<td>Execution of civil works</td>
<td>12</td>
</tr>
<tr>
<td>Manufacturing of all the equipment</td>
<td>20</td>
</tr>
<tr>
<td>Delivery of building material and equipment to the sites</td>
<td>11-23</td>
</tr>
<tr>
<td>Installation of equipment for Pole-1</td>
<td>21</td>
</tr>
<tr>
<td>Testing and commissioning of Pole-1</td>
<td>28</td>
</tr>
<tr>
<td>Testing and commissioning of bipole</td>
<td>32</td>
</tr>
</tbody>
</table>
The 3GG project is in a class of its own with regard to the very short 28 months to commissioning for monopolar and 32 months for bipolar operation. Here the knowledge and experience base provided by the 3GC project proved to be a huge asset. It profited from 3GC in most of the above listed stages of execution. Table II gives an indication on how quickly some of these stages were completed. The months are counted from zero date of the contract.

The ongoing fast and smooth testing and commissioning was particularly noteworthy. This was direct result of the experience gained from 3GC coupled with the incorporation of the majority of the engineers/supervisors from 3GC into the 3GG commissioning teams of both the Owner and the Contractor.

2.3. Reduced investment and O&M costs

The cost benefit to the Owner in terms of initial investment was considerable due to less time for engineering review, reduced type tests, repeat equipment effect, etc. There will also be significant reduction in the long-term O&M (Operation and Maintenance) costs due to the availability of adequately trained and experienced personnel.

2.4. Improvements and elimination of flaws

Already tested main equipment assured that the short delivery time did not lead to flawed or trouble making converter station equipment supplied by the contractor. Improvements in certain areas like control and protection interface were facilitated by the experience and feedback obtained from the first bipolar system. For instance, more powerful computers and I/O devices are used in 3GG.

2.5. Inter-changeability of equipment

Inter-changeability of equipment between the two bipolar systems and convenient sharing of spares between Longquan and Jingzhou converter stations will be a big practical, technical and economical advantage.

2.6. Better sharing of harmonics

The identical characteristic AC harmonic filters at Longquan and Jingzhou converter stations (see Figure 1 and Figure 2) would eliminate the possibility of improper sharing of harmonics or the problems associated with source-sink phenomenon.

2.7. Effective stabilization and frequency control strategies

The available overload capacities in the two links would help better stabilize the Central Grid, in the event of disturbances, through coordinated operation of the two links. Some of the situations where these strategies have been effectively used are:

- Emergency Power Control (Power Runback/Power Run-up) to help maintain the stability of the combined AC and DC systems at emergency conditions.
- Coordinated recovery following faults in a multi-infeed situation.
- Frequency control following loss of generation at Three Gorges complex.

2.8. Improved ToT absorption

The local manufacturing companies having ToT (Transfer of Technology) from the two similar projects had and will have immense benefits in future HVDC projects. The repeat engineering and manufacturing has/will given/give ample opportunities to better understand the processes and thereby gain much needed experience in the specialized equipment. This
ensured and would ensure that the objectives of having an increased indigenous content in the future HVDC projects are achieved with a considerably increased degree of confidence.

2.9. **Ease in future modifications and upgrades**

As the connected AC systems grow, a review of the higher-level control strategies of the different links becomes inevitable in order to make the best use of the link capabilities to stabilize and optimize the operation of the integrated AC-DC systems. The similarity of the links shall make the task of digital simulations, analyses and implementation of the determined control strategies easier.

2.10. **A step towards standardization**

Instead of having several different sizes for small differences in the transmission distances and the power transmission requirements, it’s better to have only a few standard ratings for a certain range of distances and power levels. This would not only be economical, but also provide a pool of resources in terms of redundant/identical equipments and well-experienced manpower in different areas.

3. **ACKNOWLEDGEMENT**

The authors are grateful for consent and support from their respective organizations for publication of this paper as well as valuable comments from their colleagues in its preparation.

4. **REFERENCES**


