Two series capacitors each rated at 372 Mvar supplied by ABB are in operation in the North China Power Group’s 500 kV power transmission network west of Beijing. The purpose of the installation is to enhance the power transmission capability and availability of this 500 kV grid, essential for safe energy supply to the country’s capital.

The series capacitors came on line in 2001, after a record breaking project time, less than nine months from awarding of the contract.

North China Power Group (NCPG) runs and operates North China Power Network (NCPN). It supplies an area of close to 1.5 million square kilometres and a population of about 140 million people with electric energy, including the Beijing municipality. By the end of 1997, the installed capacity of NCPG amounted to nearly 28,000 MW, with an annual production of over 140 TWh.

Particularly the capital area is undergoing rapid development, and electric power demand is growing at a steady pace. This also puts demands on development at an equal pace of the power grid on which the capital is relying for its energy supply. In this context, series compensation is an attractive as well as a very efficient means for grid reinforcement. That means, series capacitors are constructed and put into operation in the transmission corridor already existing. From a project implementation point of view, this is not only faster, but also less expensive than building new lines. Plus, of course, much less of an impact on the environment.

Each one of the series capacitors is rated at 500 kV, 372 Mvar. The series capacitors were installed each in one transmission line of a twin circuit corridor stretching between Datong and Fangshan, west of Beijing, a distance of approximately 300 km. The location of the series capacitors is about midline. With the series capacitors in operation, stable power transfer amounting to more than 1,600 MW is enabled for the twin circuit corridor. This is several hundred MW more than would have been possible without the series capacitors, i.e. the power transmission capacity of the existing corridor has been improved to a considerable degree, without any need to resort to building new lines.

The series capacitors are rated for operation not only during normal, steady-state conditions of the power grid, but also during severe system contingencies such as loss of one out of the two parallel 500 kV lines. In a case like that, the series capacitor of the transmission line remaining in service must be able to take the full load of both lines for a certain amount of time, i.e. twice the load of one line. In fact, this is one of the main reasons for having the series capacitors in the grid at all: to enable safe import of power to the Beijing area even with one line out of operation.
Some salient design features

The main protective device of the series capacitors is a varistor of ZnO type, limiting the voltage across the capacitors to safe values in conjunction with system faults giving rise to large short circuit currents flowing through the lines. A forced-triggered spark gap is furthermore utilized to enable by-pass of the series capacitors in situations where the varistor capacity is not sufficient to absorb the excess current during a fault sequence.

Finally, a bypass switch is incorporated in the scheme to enable the switching in and out of the series capacitor as need may be. It is also needed for extinguishing the spark gap in cases where the gap has operated, as the gap is not self-extinguishing.

For external faults, i.e. faults occurring outside of the segment containing the series capacitor, in all cases except the very most extreme it is required that the series capacitor is not bypassed in conjunction with the fault, i.e. the series capacitor has to stay in the circuit during and after the fault sequence in the system. After the fault has been cleared, the series capacitor is instantaneously and automatically going back into operation. The inherent speed of this procedure is crucial to system behaviour after the fault.

For internal faults, when the faulty line section is taken out by opening the line circuit breakers, the series capacitor is taken out with it. Upon a detected fault somewhere in a series compensated line section, the triggering of the spark gap, and thereby by-passing of the series capacitor, will be initiated either by the series capacitor’s own protective system, or by a command from the line protection located at either end of the power line section in question, whichever comes first. This is made possible by means of dedicated communication between the series capacitor and the line protection terminals.

Minimizing line circuit breaker stress

A particular benefit of this arrangement is that Transient Recovery Voltage (TRV) stresses on the line circuit breakers are minimized. The reason is that due to the active communication between the line protection and the series capacitor as described above, the series capacitor will always be bypassed before the actual opening of the line circuit breakers. The proper functioning of this feature has been proven by staged fault tests in the live system.

The bypass scheme, which utilizes dedicated communication channels between the line protections located in the line ends and the series capacitor located in the middle of the line, bypasses the series capacitor by ignition of the spark gap initiated from the line protections, before the line circuit breakers open. It is important that the capacitor discharge oscillation, produced by the ignition of the spark gap, is sufficiently damped when the line circuit breakers open. To accomplish this, the series capacitors are equipped with a current limiting damping circuit, which damps the 600 Hz capacitor discharge current – and thereby the capacitor voltage – to less than 10% of the first peak in less than 6 ms. The current limiting damping circuit consists of a damping resistor connected in parallel to a current limiting air core reactor.

Improvement of secondary arc current handling

The secondary arc current is the current which flows in a fault after the line circuit breakers located at both ends of a faulted line have cleared the fault. With a series capacitor installed in the faulted line, the secondary arc current will be high, due to the energy stored in the series capacitor at fault clearing. The energy will discharge in a circuit comprising the series capacitor, the line shunt reactor and the arc of the fault. This will prolong the extinction of the secondary arc current. By bypassing the series capacitor by means of the spark gap for faults on the series compensated line, the energy stored in the series capacitor will be rapidly discharged through the current limiting and damping circuit of the series capacitor. The secondary arc current will thereby be reduced to normal values, and arc extinction time will be reduced to normal.

For the Datong – Fangshan series capacitors, the spark gaps are initiated from the line protection for internal faults as described above.

Control system

The series capacitor control and protection system is based on the ABB MACH 2 concept, which is a system of both hardware and software, specifically developed for power applications. MACH 2 is built around an industrial PC with add-in boards and I/O racks connected through standard type field buses like CAN (Control Area Network) and TDM (Time Division Multiplex).

The operator interface (OWS, Operator Work Station) is a separate PC running an InTouch application placed at the operator’s desk. All operations and settings for the capacitor banks are performed from the OWS.

The series capacitors are normally unmanned. They are consequently remotely controlled through a SCADA system. If desired, they can also be locally controlled on site.

Optical Current Transducers

The control and and protection system uses optical current transducers for current measurement with optical fibres for signal transmission. This system offers several benefits:

Single-line diagram, one series capacitor
- No relay protection equipment is located on the EHV platforms;
- No auxiliary power is required on the platforms;
- The optical current transducers are powered solely by means of light generated at ground level.

The control and protection system supervises all functions of the series capacitors and provides protective action in the event of faults such as capacitor unbalance, flashover to platform, or varistor failure.

For accomplishing this, several quantities are measured by means of digital optical current transformers (DOCT):
- Line current
- Capacitor unbalance current
- Spark gap current
- Varistor current
- Platform flashover current.

The DOCT consists of a current transducer in the high voltage current busbar and an optical interface module in the control room. In the transducer, the current is sampled and converted to a digital value. This value is transmitted in the fibre system to the interface. The converter circuit in the transducer is optically powered by light sent from the interface module to the transducer in the same fibre that transmits the measured value. The transducer is operated at a sampling rate of 4 kHz, using low powering levels for the converter circuit. This allows for low power laser diodes to be used as supply power source.

### Main data (Per one series capacitor)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated system voltage</td>
<td>500 kV</td>
</tr>
<tr>
<td>Rated current per phase</td>
<td>2100 A</td>
</tr>
<tr>
<td>Rated phase reactance</td>
<td>28.4 Ω</td>
</tr>
<tr>
<td>Degree of compensation</td>
<td>35%</td>
</tr>
<tr>
<td>Rated reactive power</td>
<td>372 Mvar</td>
</tr>
<tr>
<td>Rated ZnO varistor energy</td>
<td>90 MJ/3-phase</td>
</tr>
</tbody>
</table>

### Interface Operator

- Screen & keyboard 1
- Screen & keyboard 2
- OWS/SER server 1
- OWS/SER server 2
- Printer

### Control & Protection

- HDLC communication & Supervision Board
- High performance DSP Board
- Optical Interface Board (OIB)
- Ethernet board (OIB)
- Ethernet board (TCP/IP)
- PC Motherboard
- Pentium processors

### Main Circuit

- Ambient temperature measurement
- Orders to & indications from breaker and disconnectors
- Digital input
- Digital output
- Current measurement
- Communication with MAC2 PC

### Layout, one series capacitor phase

1. ZnO Varistor
2. Capacitor Bank
3. Control Platform
4. Trigger
5. Spark Gap
6. Reactor
7. Ladder
8. By-pass Switch
9. OCT
10. HV Signal Link
11. Damping Resistor