About two and a half years ago, on 14th February 2003, the HVDC East-South Interconnector Project had been dedicated to the nation by the Prime Minister of India, Mr. A.B. Vajpayee, in an inaugural ceremony at Kolar, in the state of Karnataka. Siemens Power Transmission & Distribution Group as contractor had thus completed successfully India’s largest power transmission project in a record time, ahead of schedule. Linking the states of Karnataka and Orissa over a distance of 1,450 kms, this sophisticated state-of-the-art High Voltage Direct Current (HVDC) transmission system - the second longest HVDC link of the world - has been transferring a bulk power of up to 2,000 MW from the Talcher power generation centre in the eastern part of India to Kolar near Bangalore, the hub of a rapidly developing industrial and high-tech area in the south.

The East-South project was the eighth in a series of HVDC links in India (today the total number is nine), interconnecting its five asynchronous regional power grids, thus making a flexible power transfer between them based on supply and demand possible. Taking advantage of the local resources, e.g. coal reserves in central and eastern regions, and hydroelectric power in the north and south, the HVDC links (Fig.1) have contributed successfully to the creation of a nation-wide grid, the completion of which till 2012 with 30,000 MW of inter-regional transmission capacity is planned by Powergrid, the largest power transmission utility of India.

The network planners of India have in this regard made use of the excellence of HVDC technology as the only alternative, when conventional ac transmission system proves neither technically nor economically feasible for interconnection of asynchronous (dissimilar) grids, and/or for power transmission over large distances between power generation and load centers.

An HVDC system operates on the principle of conversion of alternating current (ac) into direct current (dc) and vice versa by using converter valves. Of the two types of HVDC systems: long distance and back-to-back, East-South belongs to the first one, with the rectifier (ac-> dc) and inverter (dc-> ac) stations far distant from each other. The rectifier station is for example located at Talcher in Orissa and the inverter station in Kolar near Bangalore. In a back-to-back system instead, both the rectifier and inverter are accommodated in the same station with practically zero transmission distance between the two interconnected adjacent ac grids.
Key Components of the East-South System

The heart of an HVDC system is its **Converter Valves** for ac ↔ dc conversion. These consist of modules with powerful thyristors with high current ratings and steadily increasing blocking voltages.

Figure 2 shows the completely assembled converters, arranged as three quadruple valves, for one pole of the East-South system. The 12 modules in total needed to make a quadruple valve are best arranged as a twin tower as can be seen in Fig. 2.

The converter twin towers are suspended from a special ceiling construction of the valve hall, and all connecting components between the modules like suspension insulators, buswork and pipings are of flexible design to ensure maximum seismic stress withstand capability.

To reduce the risk of any fire to a minimum, exclusively flame-retardant materials for insulation and barriers within the converter valves are used. The modular structure of the valves has not only simplified replacement of any faulty component, but also transportation and installation as a whole.

Between the converter valves and the ac grids, on both sides of the ±500 kV dc transmission line, are the **Converter Transformers** (see Fig. 3), another key component of an HVDC system. In the rectifier station Talcher, they transform the eastern ac grid voltage of 400 kV down to a value, as is optimal for the converter valves, based on design calculations. In Kolar, where dc is converted back to ac, the converter transformers do the reverse, i.e. step up the voltage from the valve side to the level of the southern ac grid (also 400 kV), thus completing the interconnection.

Converter transformers experience combined ac & dc stresses in the winding insulations, high harmonic content in the current and need special competence and skill in design, construction and testing, compared to conventional ac power transformers.

The HVDC system basic design calculated and defined important parameters of the transformers like short circuit impedance, on load tap changer range etc., taking consideration of all special factors such as the permissible s.c. current of the thyristors, operation requirements at reduced dc voltage as also at high firing angles.

Another key component is the **Smoothing Reactor** which limits the dc fault current as also suppresses the dc harmonics to a permissibly low level. In the design phase, calculations considering different dc circuit configurations were carried out for an adequate dimensioning of the smoothing reactor, which is installed outside the valve hall and connected to the 500 kV dc valve hall bushing.
The harmonics mentioned above, which the smoothing reactor is supposed to limit, are a necessary evil of the current conversion process in the converter valves. The converters are sources of harmonics, which if allowed to infiltrate unhindered into the ac or dc systems, would distort the system voltage. The dc harmonics can be kept within specified levels by an adequately designed smoothing reactor in combination with DC Harmonic Filters. For absorption of the ac harmonics, AC Harmonic Filters are needed. They are tuned to the specific frequencies of the harmonics aimed for elimination. The ac harmonic filters are installed in the outdoor ac switchyard (Fig. 5) and connected to the 400 kV ac bus. The dc filters, located behind the smoothing reactor, are connected to the outgoing or incoming 500 kV dc line at the rectifier or the inverter station respectively (Fig. 4).

Not only that the converters generate harmonics. Depending on the art of converter control as well as the commutation process, an amount of phase shift between the fundamentals of ac current and voltage occur, causing a demand in reactive power which has to be met.

Unless a proper balance of the reactive power demand in the system is achieved, inadmissible fluctuations in the ac grid voltage may occur. The same ac filters that absorb the ac harmonics, offer here a dual function. They provide this reactive power, and in a detailed reactive power management study, out of a combination of all reactive power elements: ac filters, shunt capacitors, on need also shunt reactors, the optimal choice is made to establish this balance.

The Control & Protection System is as if the central nervous system of an HVDC. A fully redundant and digitised powerful control and protection system has been implemented in the East-South system, that guarantees not only an optimally controlled energy transmission and adequate protection of all station components, but is also easy to handle and user-friendly, including an operator interface based on the most recent computer technology. The control system maintains the power transmitted at the desired level, co-ordinating the switching of reactive power reactive elements as per reactive power demand over the specified range of operation, optimising the power ramp-up or ramp-down rate with predefined values, and performs numerous other control and monitoring functions during dynamic power changes, based on predetermined ac system parameters.

The protection system ensures selectively a safe disconnection and isolation of the faulty equipment, avoid unnecessary shut downs of the system, and prevent damage of HVDC components as far as possible caused by faults or overstresses.
Interfaces to remote control facilities from load dispatch centers and telecom interface to corresponding converter station for exchange of monitoring data are integrated into the operator control level. So the Eastern or the Southern Region Load Dispatch Centre (ERLDC or SRLDC) of the Indian grid can thus take over the control of the HVDC system on need.

Fig. 6 shows the control room at Talcher converter station with visual display units (VDU) and the Mimic boards.

As is customary for Siemens, the complete hardware and software of the East-South control and protection system was subjected to intensive off-site testing (Functional Performance Test) in Germany. All control and protection functions as also the redundant systems could thus be thoroughly checked prior to shipment. This reduced the on-site commissioning time considerably.

The ground electrode line connects the neutral point of the bipole of an HVDC to the ground electrode. The location of the ground electrode, depending on soil condition, may have to be chosen tens of kilometers distant from the converter stations. In such a case, monitoring and protection of the electrode lines leaving the converter station (Fig. 8 shows the electrode line terminating tower at extreme left) and connecting the ground electrode at the other end, is an essential task. The advanced, highly reliable Pulse-Echo Monitoring System (PEMO) developed by Siemens has been implemented for East-South for this purpose. The electrode lines at both stations are about 35 km long. The PEMO technique has very less primary components compared to the conventional system with blocking filters. It can locate any fault on the electrode line and detect its type, and is relatively insensitive to component tolerances and environmental conditions.

Extensive civil works had to be carried out at both Talcher and Kolar converter stations:
- The valve halls to accommodate the suspended thyristor valves, one hall per pole, with the control building and auxiliary service buildings in between. Although the major part of the heat generated in the valves due to its high power density is carried away by an adequately designed valve cooling system, a fraction dissipates into the air and the valve halls are ventilated to maintain the inside air temperature within the allowable level. The control rooms are fully air-conditioned.
- The complete area of the outdoor switchyards (ac and dc) including harmonic filters, their foundations, fencing etc.

Numerous ancillaries and their accommodation e.g. for diesel generator sets, pump houses, fire fighting equipment, oil handling equipment add to the scope.

The civil portion as well as a considerable amount of the ac switchyard equipment, ac protection, auxiliary power supply and other ancillaries was within local scope, procured and executed by Siemens India.

**Operational Experience since commissioning**

Since the very start of its commercial operation two and a half years ago, the East-South Interconnector has firmly established itself in the Indian grid map as an indispensable and reliable HVDC link. By making use of the inherent dynamic power change possibilities through HVDC control when ac system disturbances or faults occur, this link is contributing to the stability of the interconnected regional ac networks as well.

India is a country with potential for HVDC business. In their endeavour to meet the increasing power demand of the sub-continent, bridge ever longer transmission distances with bulk power, Powergrid is also studying the feasibility of higher DC transmission voltages in near future.

The next HVDC link planned by Powergrid is Ballia – Bhiwadi, a 2,500 MW long distance transmission system stretching from north-east to the north of India.
## Project data: East-South HVDC Interconnector II, India

<table>
<thead>
<tr>
<th>Turnkey Project</th>
<th>HVDC Transmission linking Talcher Substation with Kolar Substation, 2,000 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractor:</td>
<td>Siemens</td>
</tr>
<tr>
<td>Total Value:</td>
<td>~ 200 million Euro</td>
</tr>
<tr>
<td>Transmission Length:</td>
<td>1,450 km</td>
</tr>
<tr>
<td>Commercial operation:</td>
<td>Since February, 2003</td>
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</tbody>
</table>

| Converter Valves | 3,888 nos. Electrical Triggered Thyristors (ETT) |
| Converter Transformers | 7 nos. single phase, three winding design, rated at 397 MVA (incl. 1 spare transformer) | 7 nos. single phase, three winding design, rated at 397 MVA (incl. 1 spare transformer) |
| Smoothing Reactor | 250 mH reactor of dry air-core type/pole; 500 kV dc rated voltage; 2,000 A rated current | 250 mH reactor of dry air-core type/pole; 500 kV dc rated voltage; 2,000 A rated current |
| Harmonic Filters | 6 nos. double-tuned (DT) AC filter 12/24, 120 MVar each; 3 nos. DT AC filter 3/36, 97 MVar each; 1 no. Shunt Capacitor, 66 MVar; 2 nos. Shunt Reactor, 80 MVar each | 6 nos. DT AC filter 12/24, 120 MVar each; 3 nos. DT AC filter 3/36, 97 MVar each; 5 nos. Shunt Capacitor, 138 MVar each |

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