THE CHANDRAPUR - PADGHE HVDC BIPOLE TRANSMISSION

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1. PROJECT BACKGROUND

The Chandrapur Thermal Power Station of MSEB has an installed capacity of 2340 MW. Furthermore, MSEB’s share of 577 MW, from the National Thermal Power Corporation’s (NTPC) Korba Super Thermal Power Station, is received at Chandrapur over the 400kV double-circuit Bhilai-Chandrapur line of the Power Grid Corporation of India Ltd. (PGCIL). Goa, under normal conditions, and Gujrat, under emergency conditions, also receive a share of NTPC power via MSEB’s transmission system. Furthermore, PGCIL has also established a 2x500 MW HVDC back-to-back station at Bhadravati, near Chandrapur, for interconnection of the western region and southern region. MSEB is expected to receive power assistance from the southern region over this back-to-back HVDC link during peak hours. Even if the above mentioned assistance is not considered, the total power over Chandrapur’s 400kV bus is around 2700 MW.

The exiting transmission network, consisting of three 400kV circuits between Chandrapur and Mumbai, can safely transmit around 1200 MW of power without consideration to any contingency outages. Therefore, it was necessary to provide additional transmission capacity of around 1500 MW. Expansion of the 400kV transmission network by constructing several 400kV lines was not feasible due to severe right-of-way constraints. For this reason, two other options—construction of an 800kV link, and a HVDC bipole—were considered. The HVDC bipole option was preferred because of the various advantages it offered. Ultimately, after clearance by the CEA and the Planning Commission, MSEB constructed a 1500 MW ±500kV Chandrapur-Padghe HVDC bipole.

Before determining the salient parameters of the project, extensive technological-economic studies were carried out...
with voltage levels ranging from +/- 350kV to +/- 600kV, and line conductors ranging from 0.4 square inch copper equivalent ACSR Zebra to Bersimis, with triple and quadruple bundling. The costs for insulation of lines and terminals vary with voltages, whereas the cost of conductors and losses vary with current ratings. An adequate evaluation factor was considered for losses. It was observed that the optimum voltage range for the DC link was +460kV to +550kV. Because it is a widely used voltage, +500 kV was adopted. For use as line conductors, Bersimis ACSR (having a good aluminum to steel ratio) was chosen for its loss reduction characteristics.

2. FINANCING

The World Bank studied, on MSEB’s request, a total project with the following components:

- 500 MW addition to the Chandrapur power plant.
- Converter terminals.
- HVDC line with electrode and electrode lines.

The World Bank found the project viable and agreed to partly finance the power plant and the HVDC line. For local components of the HVDC line, MSEB arranged financing primarily from the Power Finance Corporation (PFC).

For the converter terminals, MSEB requested financing proposals from the bidders.

The successful ABB/BHEL proposal included multi-source financing, arranged as follows:

- Grant from the Swedish aid agency SIDA
- Soft-loan from the Swedish aid agency BITS
- Commercial financing from international banks, guaranteed by Swedish export credit insurance, EKN.
- Commercial financing from international banks, guaranteed by German credit insurance, Hermes.
- Commercial financing from international banks, guaranteed by Swiss credit insurance, ERG.
- Commercial financing from international banks.

The above financial proposal was accepted by MSEB and the project was financed as planned. In spite of its complicated structure, the arrangement worked well.

For the local component, there were three alternatives given in the tender:

- Deferred credit
- Bonds
- Leasing

Although MSEB selected the leasing alternative, this was not possible to accomplish during the project, mainly due to its complicated nature. Instead, financial assistance from PFC was later introduced.

3. SYSTEM DESIGN

3.1 Basic Rating

The Chandrapur-Padghe HVDC bipole is rated for 1500 MW continuous power flow, a two-hour overload rating of 1650 MW and a five-second overload rating of 2000 MW. The two-hour overload capability can also be utilized continuously at low ambient temperatures, i.e., below 33° C. The minimum power flow is set at 75 MW in monopolar operation. The link is operated at a direct voltage of ±500 kV. On the AC sides, the link is connected to the 400 kV system in both Chandrapur and Padghe. The AC voltage is allowed to vary between 380 kV to 430 kV in Chandrapur and between 360 kV to 420 kV in Padghe. The frequency can vary between 47.5 Hz and 51.5 Hz.

There are four AC filter banks at both stations. Each bank is rated at 200 MVA. There are two DC filter branches per pole and per station.

![Fig. 1. Single line diagram of the transmission link.](image-url)
3.2 Operational modes

The DC link can be operated in a number of operational modes as described below. Some operational modes can be utilized jointly.

Balanced bipolar mode: In this mode, the unbalanced current flowing through the ground is regulated to maximum 10 A.

Monopolar mode with ground return: In this mode, the electrode lines, together with the ground electrode lines and ground electrode of each station, are utilized as a return path.

Monopolar mode with metallic return: In this mode, the line conductors of the unused pole are utilized as a return path with one ground electrode isolated (at the Chandrapur end).

Reduced DC voltage: The link can be operated at 400 kV DC during deteriorated insulation conditions of the line at a power rating of 1000 MW. This can be set up to 500 MW at each pole.

Reverse power operation: The normal power flow is from Chandrapur to Padghe. The link can also transmit up to 1466 MW of power in the opposite direction.

Reactive power control: By switching filter banks in and out, either the reactive power exchange or the AC line voltage will be maintained at set values with dead bands set by the operator.

Islanded operation: Major disturbances in the AC system sometimes result in total power failure due to cascading. The HVDC link can be islanded on the generator sets at Chandrapur and generation limited in the Mumbai area. If the Chandrapur generators are islanded, i.e., operated with the HVDC bipole connected only, a frequency controller will hold the frequency of the machines to 50 Hz and thereby maintain power in the Mumbai area as well.

3.3 Performance Parameters

The HVDC system is designed to operate with an energy availability of 99% and a reliability margin that permits a maximum of ten pole outages per year. Because the design is such that the poles operate independently, bipolar outages are virtually ruled out. The good availability and reliability figures are achieved with high quality components and a strategy of redundancy throughout the system.

The guaranteed losses are 0.1% no load and 0.7% load losses per station. These very low figures have been achieved by using low-loss transformers and thyristor valves.

4. SPECIAL FEATURES

Duplicated control system. The fully computerized control and protection system has been duplicated with one active system and one hot standby system. This will ensure high reliability and availability of the HVDC system.

Active DC filter. Active DC filtration for an overhead line transmission has been provided for the first time. See 6.3.

Power modulation. The HVDC link will operate in parallel with the 400kV and 220kV AC systems. In case of system disturbances, there is a possibility of power swing in the AC network. With the facility of rapid variation of power flow over the HVDC link, the power oscillations of the parallel AC system will be substantially reduced, resulting in improved system stability.

Transfer between metallic and ground return. Special equipment is included in the system so that transfer can be made without interruption to the power flow.

Master control location. This can be located at Padghe, Chandrapur or Kalwa (load dispatch). In Chandrapur and Padghe, the control can be operated from SCADA, MIMIC or the back-up MIMIC. Selected control signals can also be issued from the Kalwa load dispatch center.

Electrode line supervision. By active supervision of the electrode lines, it will even be possible to detect high impedance faults.

Loss Optimization. On the HVDC system, the active power flows over long distances and the requirements for reactive power are met at each terminal locally. Therefore, transmission losses are less when compared to an equivalent AC system. The voltage profile in the AC network is also improved. This feature is utilized for optimization of system losses by optimally controlling power flow over the DC link. Suitable provisions have been made in the Energy Management System at the Kalwa Load Dispatch Center for continuously assessing the optimal power requirements for the HVDC link.

5. MAIN CIRCUIT EQUIPMENT

The thyristor valves housed in the valve halls (26 m high) make up the heart of the HVDC system. The valves are water-cooled with a closed loop, single-circuit cooling system. The thyristor valves are of a suspended design, resulting in a valve structure able to withstand even severe earthquakes. Each suspended valve consists of four single valves combined into one mechanical unit called a quadruple valve (Fig. 3). The high potential end of the quadruple valve is at the point of suspension (i.e., towards the ceiling). The light guides for control and the water pipes for cooling enter at the low potential point (i.e., close to the floor). One quadruple valve consists of 384 series-wired thyristors, each with an area of 45 cm² and able to conduct full current of 1700 ADC with a maximum voltage rating of 7 kV. Each quadruple valve weighs 30 tons.
The converter transformers are of a single-phase, three-winding OFAF type (Fig. 4). Three of its bushings will protrude directly into the valve hall. The necessary delta connection is made inside the valve hall and the neutral point of the star connection is made outside, thereby eliminating the need for wall bushings. Each of the three transformers has a rating of 300 MVA per pole and a total weight of 359 tons. Each converter station is provided with a spare, single-phase converter transformer unit. A permanently installed rail transfer track system will enable fast replacement of converter transformers, if and when required. The converter transformers in Chandrapur and Padghe are of the same design, making it possible to use the spare transformer from Padghe at Chandrapur and vice versa.

The smoothing reactors are of the iron core, oil-insulated type. One of the smoothing reactor bushings protrudes into the valve hall, thereby eliminating the need for wall bushings. There is one smoothing reactor per pole and per station, and one spare per station. The smoothing reactors are rated at 566 kVDC, 360 mH and 1700 ADC.

The neutral connection between the valve hall and the DC yard is made by neutral cables with a two out of three redundancy. With this arrangement, wall bushings are not necessary in the plant.

6. AC AND DC FILTERS

Harmonics of various orders are generated by the HVDC converter on both AC and DC sides. AC filters are installed to filter harmonics on AC side where as DC filters are installed to filter harmonics on DC side. Chandrapur and Padghe converter stations are provided with identical high pass type of filter banks for achieving performance parameters under wide AC system fundamental frequency variations.

6.1 AC Filters

At Chandrapur as well as Padghe converter station a total of 800 MVAR AC filter bank is provided which is divided in four equal sized banks of 200 MVAR each. Two numbers of one type of bank are provided which consist of
120 MVAR HP12 filter and 80 MVAR HP24/36 filters. Two numbers of another type of bank are provided which consist of 120 MVAR HP12 filter and 80 MVAR HP3 filters.

6.2 Passive DC Filter
The DC filters are arranged as double tuned filter branches and active DC filters. One branch each of 2/6th and 12/24th harmonic double tuned filters are provided for each pole at DC side of Chandrapur and Padghe converter stations. Due to the fact that the DC line length is close to quarter wavelength, 2nd harmonic resonance was foreseen. 2/6th harmonic filter is provided to reduce the effect of 2nd harmonic resonance. DC capacitor of 2/6th harmonic filter is the largest DC capacitor, of 2 mF and 650 kV DC rating, installed so far. The 12/24th filter is also equipped with an active part whose details are given below.

6.3. Active DC Filter
The traditional means to reduce the harmonic current into the DC line has been to use passive filters consisting of RLC elements. Besides passive filters, the Chandrapur-Padghe HVDC Bipole Project is provided with active filters to further minimize possible disturbances to nearby tele-communication lines.

The principle of an active filter is to inject in the DC line a controlled current consisting of the harmonic currents not eliminated by the passive filters, but with each component in phase opposition, so that a cancellation of harmonic current occurs thus eliminating harmonics on DC side. A simplified description of the process taking place in each pole at each station is given below.

The principal circuit is given in Fig. 5. The harmonic currents entering the line are measured by means of a Harmonic Current Transducer (HCT), placed at pole level. This HCT transmits the signal to ground level by means of fiber optics. The signal is then processed with the help of a control unit. The control unit regards the harmonic current entering the line as the “error” of the control loop. The control unit considers then the different transfer functions of the passive filters, transmission line, etc., and with this information, processes the “error” signal so that a counter signal is generated.

The counter signal is then amplified by a very powerful amplifier (several hundreds of kW), and transformed into the correct impedance level by means of a high frequency transformer. The high frequency transformer has its secondary winding connected between the bottom of the passive filter and the DC Neutral Bus. Being at the neutral end, the transformer serves the purpose of achieving the necessary insulation level without imposing high voltages on the amplifier.

7. AUXILIARY POWER SYSTEM
To achieve the desired reliability and availability of an HVDC link, the auxiliary power system is of utmost importance for the critical functions of the HVDC link—functions such as valve cooling, converter transformer cooling, smoothing reactor cooling, SCADA, control and protection, mechanical auxiliaries, etc. Therefore, the highest priority was given to the design of auxiliary power system. The auxiliary power system was designed to include a high degree of redundancy for example double DG sets in both ends and UPS system for valve cooling.

8. INTER-STATION AND INTER-CONTROL CENTER COMMUNICATIONS SYSTEMS

8.1 General
Over the years, MSEB has developed its own communications network to meet its communications requirements for speech, data transmission, protection, etc., to control and regulate the rapid and continuously growing power system. This communications network is mainly comprised of Power Line Carrier Communication (PLCC).

The PLCC is inadequate in meeting the communications demands for MSEB because of such inherent limitations as limited bandwidth, susceptibility to electromagnetic interference, frequency congestion, etc. Optical communication is the best alternative for overcoming these problems.

8.2 Optical Communications
In consideration to the above, MSEB decided to establish an optical link between Chandrapur and Padghe by using Optical Ground Wire (OPGW) as one of the ground wires on the Chandrapur-Padghe HVDC line. Padghe will be
further connected to the Kalwa Load Dispatch Center by providing OPGW on one of the existing 220kV lines. In the OPGW of the above link, 24 nos., single-mode dispersion shifted, 1550 nm fibers are provided. The optical link shall have two interface stations where signals can be added or removed as required, and five through-repeater stations, where signals are regenerated for further transmission. Through these interfaces and repeater stations, it is proposed to establish exclusive communications interconnections in due course. The optical equipment is synchronous digital hierarchy (SDH) of the first order, i.e., STM-1 or 155 Mb/s. When fully equipped, the optical equipment will be able to support 1,920 channels.

8.3 Future plans
On completion, the Chandrapur-Padghe- Kalwa optical link will serve as a state-level communications highway where channels can be added or removed through mediums such as microwave, PLCC, etc. After attaining the required number of fibers and terminal equipment capacity to meet the HVDC requirements, MSEB intends to commercially utilize the remaining fibers and terminal equipment capacity.

9. SCADA
A dual redundant computer system for Supervisory Control And Data Acquisition System (SCADA) has been provided for both the converter stations. HVDC control and monitoring is performed from SCADA by means of VDUs and keyboards. Both AC and DC systems can be controlled from SCADA in local station as well as remote station. The system has been customized for simple and fast control and efficient data retrieval. Graphic displays including MIMIC diagrams having same presentation as station MIMIC panel has been provided for ease of operator control. The system provided can monitor above six thousand signals, both analog and digital, and store them with high resolution both for real time display and post fault analysis. Alarm / event summaries, historic trends etc. are available to the operator. Man machine interfaces are handled by Operator Work Station (OWS), Engineer Work Station (EWS), VDUs and printers.

10. SALIENT FEATURES OF THE TRANSMISSION LINE
Salient features of the DC line are as follows:

i) Route length: 752 km.

ii) Conductor details: Bersimis ACSR with 42 nos. aluminum strands of 4.57 mm diameter and 7 nos. steel strands of 2.54 mm diameter.

iii) Number of sub-conductors per pole: 4 nos. with sub-conductor spacing of 457 mm.

iv) Line resistance per km: 0.0105 ohms.

v) Details of ground wires: Two ground wires, of which one is an 80 square mm, 100% aluminum alloy conductor and the other is a 13.59 mm diameter, optical ground wire.

vi) Minimum ground clearance: 13.5 meters.