THE SECOND 1 x 500 MW HVDC BACK-TO-BACK INTERCONNECTION AT VIZAG

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Abstract

The Second 1 x 500 MW HVDC Back-to-back station is located very near a similar 1 x 500 MW HVDC BtB project already implemented in the first phase by Powergrid. The second 500MW interconnection, which has been commissioned recently has increased the direct inter-regional power transfer capability from the Eastern to Southern regions to a total of 3000 MW. Both the back to back stations are operating in parallel.

A back-to-back HVDC converter can be used when two asynchronous AC systems need to be interconnected for bulk power transmission or for AC system stabilization reasons. In an HVDC back-to-back station there are no overhead lines or cables separating the rectifier and the inverter, hence the DC current can be kept high and the DC voltage low. The low DC voltage means that the air clearance requirement is low, which favours a compact design of the valve hall.

The back-to-back HVDC converter station at Vizag is of the conventional type with indoor thyristor valves and smoothing reactors located outdoor. The HVDC Back-to-back utilizes a special mid-point (6 pulse bridge) grounding design for the thyristor valves on the southern side with two smoothing reactors installed in series on the neutral side.

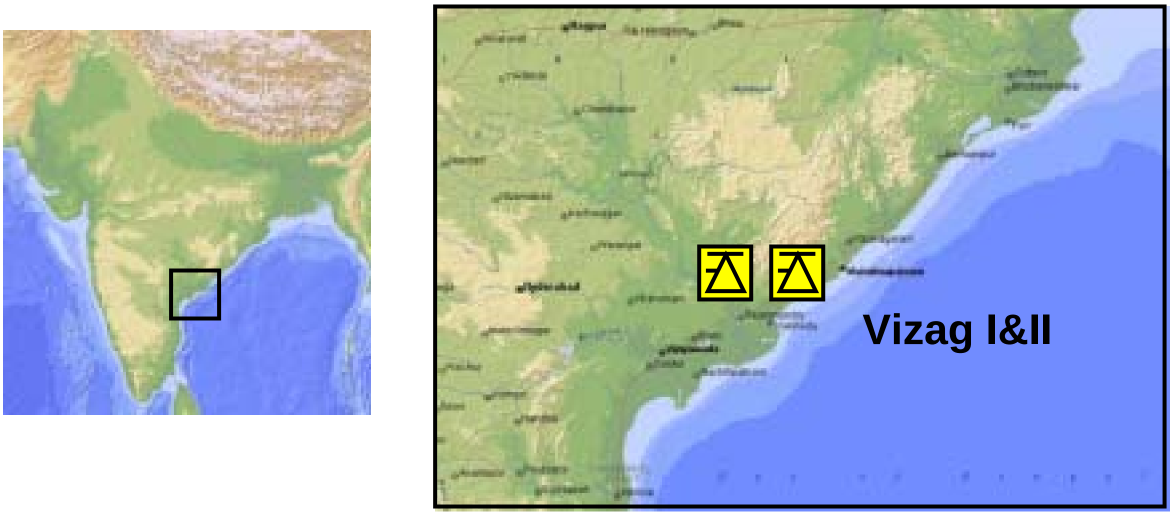
This paper intends to cover the overall scheme including associated AC network, main circuit arrangement, layout, filtering scheme including any new features adopted, an overview of the control and protection schemes, the higher level control features and strategies adopted. The paper also mentions the protection provided for mitigation of ferro-resonance which may occur during operation of series compensation on the 400 kV lines on the Eastern side.

The paper will also cover the major system and commissioning tests consisting of high voltage energisation, power flow and tests of all major controls.

1.0 THE SECOND 1 x 500 HVDC PROJECT AT VIZAG

1.1 Introduction

The HVDC back-to-projects at Vizag are part of Powergrid's East-South Interconnections. The first 1 x 500 MW HVDC project was commissioned in 1999 thus enabling power transfer from the Eastern region to the Southern region. The next step in the interconnection was the construction of the 2000 MW HVDC bipole between Talcher in the Eastern region and Kolar in the Southern region. This bipolar HVDC long distance transmission with a line length of around 1370 kms. was completed and commissioned in 2002 and forms the East-South Interconnector-II. The second 1 x 500 MW HVDC project at Vizag forms the East-South Interconnector-III.



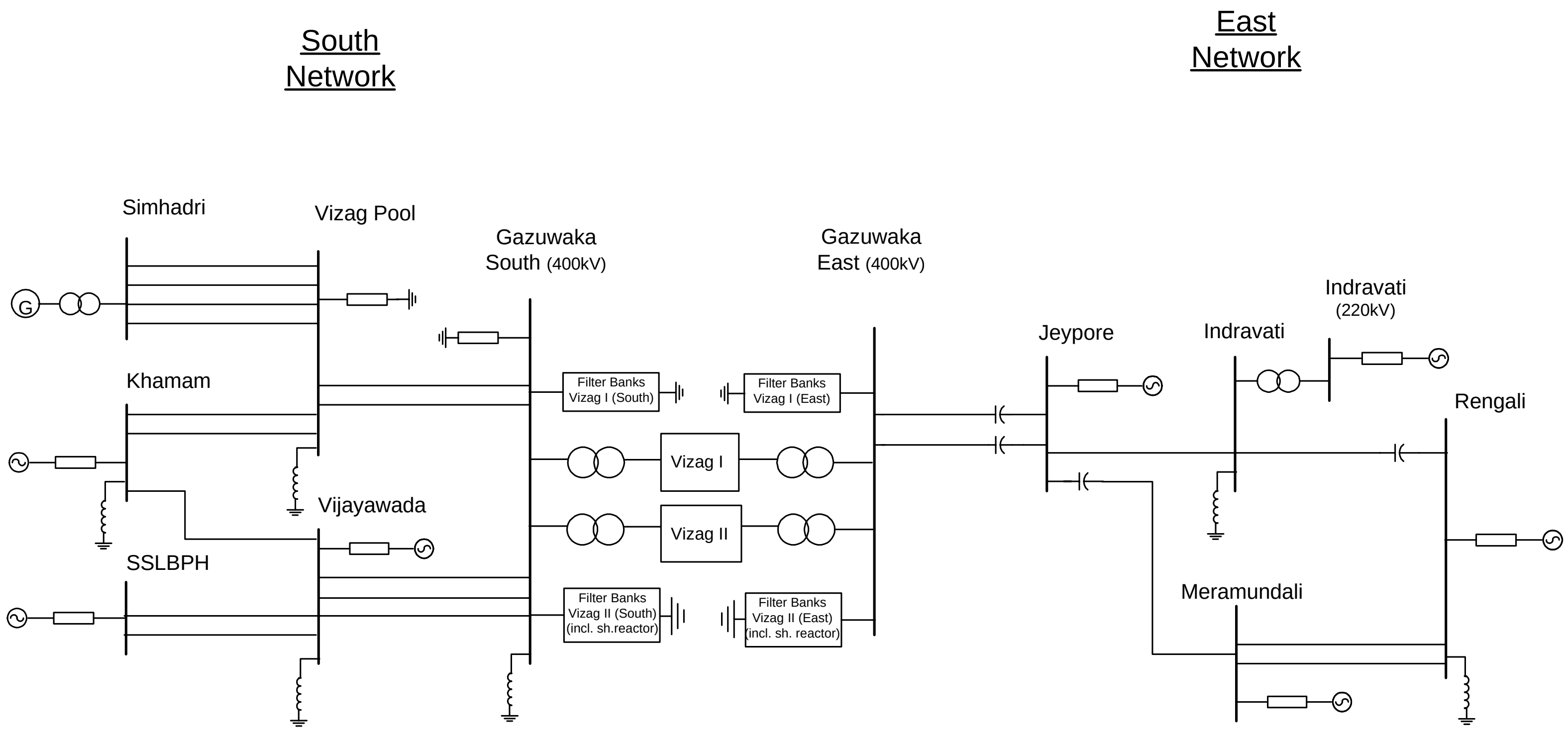
Figure(1)   Map of India showing geographical location of Vizag I & II

The second phase is very similar to the first 1 x 500 MW back-to-back, employing similar modular back-to-back converters, with classic line commutated converters. Both the phases link the 400 kV networks of the Eastern region and Southern region. The connection to the Eastern Region network in Orissa is by 400 kV double-circuit transmission lines, nearly 225 km in length, running from the Vizag-I East bus to the Jeypore 400 kV substation in Orissa. Both the systems operate at 50 Hz.

A simple one line diagram for the a.c.network in given in fig (2) below.

It can be seen that the lines to Jeypore from the East bus have series capacitors compensating up to 50% line inductance, installed at the Jeypore end. This series compensation is part of the transmission network planned with the Second 1 x 500 MW HVDC block at Vizag.

Figure (2) AC Network around Vizag HVDC Station



Vizag HVDC back-to-back: AC Networks

2.0 SYSTEM ASPECTS

The two electric systems are rather large, yet the connection to the Eastern region, is at a relatively weak point in it's network. The Southern Region system has an installed capacity of about 25000 MW. The minimum short circuit capacity at the HVDC station at Vizag(South) was defined as 2500 MVA considering both blocks operating at overload power of 1100 MW. This could however vary widely and based on actual network studies was determined to be as high as 8000 MVA, depending on the number of connected generators at Simhadri and the status of the interconnecting lines to Khammam and Vijayawada. When compared to the first phase of the interconnection, 4 nos. 400 kV lines have come up, one double-circuit each to Khammam and Vijayawada, thus considerably increasing the short circuit level at Vizag (South).

The connection point to the Eastern region is defined at the Vizag 400 kV substation East bus. The Eastern Region system has an installed capacity of 15000 MW, but the Vizag (East) bus, at the end of a 225 km long line from the Jeypore 400 kV sub-station located in Orissa which is quite remote from major generators like Talcher which is about 500 kms. away. At the time set for commercial operation of the phase one, the lowest short circuit capacity at Vizag (East) was defined as 1200 MVA (with only one line to Jeypore and no series compensation). Based on actual network studies the short circuit capacity could be as high as 3000 MVA.

3.0 STATION CONFIGURATION AND LAYOUT

Figure 3.0 gives the single line overview of the Block-2. The Block-2 is essentially similar to Block-1, supplied by a different manufacturer. The main difference is the configuration and arrangement of the thyristor valves. The operating voltage with respect to ground is only about half of the pole voltage due to the mid-point grounding adopted here for the converter valves. The junction between the two 6 pulse bridges for one of the sides (Southern side in this case) is grounded through the smoothing reactor. The smoothing reactor is in itself split into two halves each of 30 mH, the mid-point of which is grounded. As the station is a back-to-back with no part of the d.c. side exposed to atmosphere, the above configuration is compatible in terms of overall insulation coordination. The nominal direct voltage to ground is +/- 88 kV.

On the Southern side the 400 kV a.c. bus is an extension of the existing bus to which the Block-2 a.c. side is also connected. On the Eastern side the interconnection of Block-2 is through section breakers and a short span of 400 kV line of about 0.5 km in length. The main station occupies an area of roughly 500 x 150 m and covers the following areas:

- Valve Hall and Service Building
- Converter Transformers
- Smoothing Reactor
- AC Yards and filter for East and South sides
- Shunt Reactor

∉#Auxiliary buildings like diesel generator and fire fighting pump house
∉#33kV auxiliary station

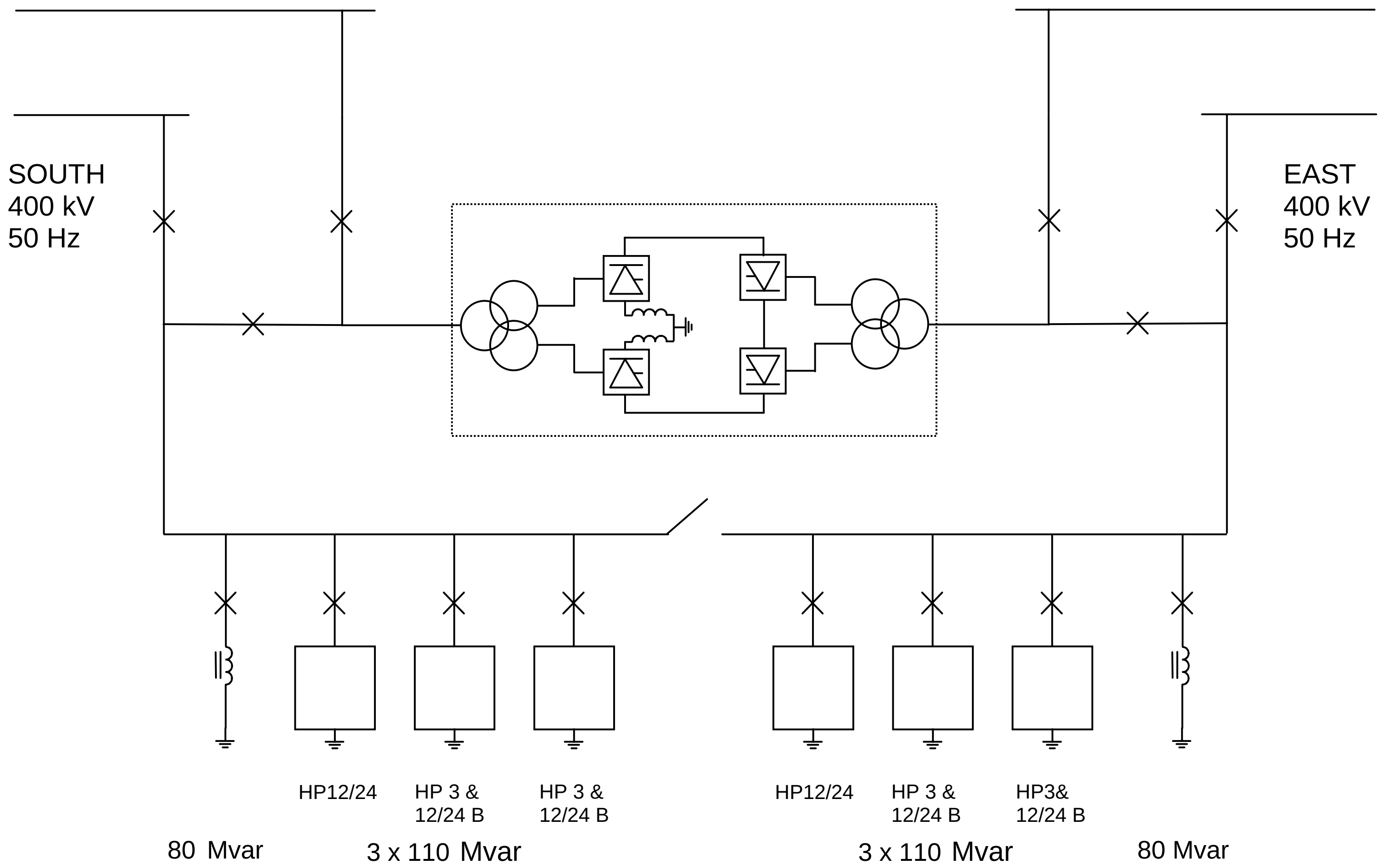


Figure (3) Single Line Diagram

In addition to the main area there is an extension bay area for interfacing with the existing Block-1 East bus. A short 500 m. overhead line connects the Block-2 main area to the Eastern extension. The main items will be briefly explained herein.

3.1 Filtering and Reactive Power Control

The filter banks have been designed to be identical for the South and Eastern sides although the impedance diagrams are not exactly the same for both the regions. They consist of an HP-12/24 section forming the base and two numbers of a combination of HP 12/24 and HP3 branches giving the additional filtering and reactive power support required at higher power levels. All the switchable banks have identical rating of 110 MVAr.

In addition to the shunt filter banks, one shunt reactor of 80 MVAr each has been provided on each side. The shunt reactors are rated to consume 80 MVAr at a nominal voltage of 400 kV.

The total fundamental frequency rating for the filter bank is 330 Mvar for the 500 MW converter. In addition the PLC filter also gives about 12 MVAr net. Fig. 4.0 gives the reactive power exchange limits that need to be maintained with the a.c. network for all values of power flow on the HVDC back-to-back from minimum power till the 2 hour overload power level. These limits as per the project Technical specifications are defined for power flow in either direction. These limits have to be maintained for all variations of the a.c. network configuration and voltage variations within +/- 5% and frequency variation in the range 47.5 Hz to 50.5 Hz.

To achieve the above, the back-to-back control scheme, apart from adopting filter switching can also use variation in the converter firing angles. The firing angles for the Vizag back-to-back can be increased to as high as 63 deg. electrical. The Reactive Power Controls also limit the a.c. voltage step at filter switching to within +/- 5% as stipulated in the project Technical Specifications. All the capacitors required for the AC and PLC filters have been supplied from ABB's works in Bangalore, India.

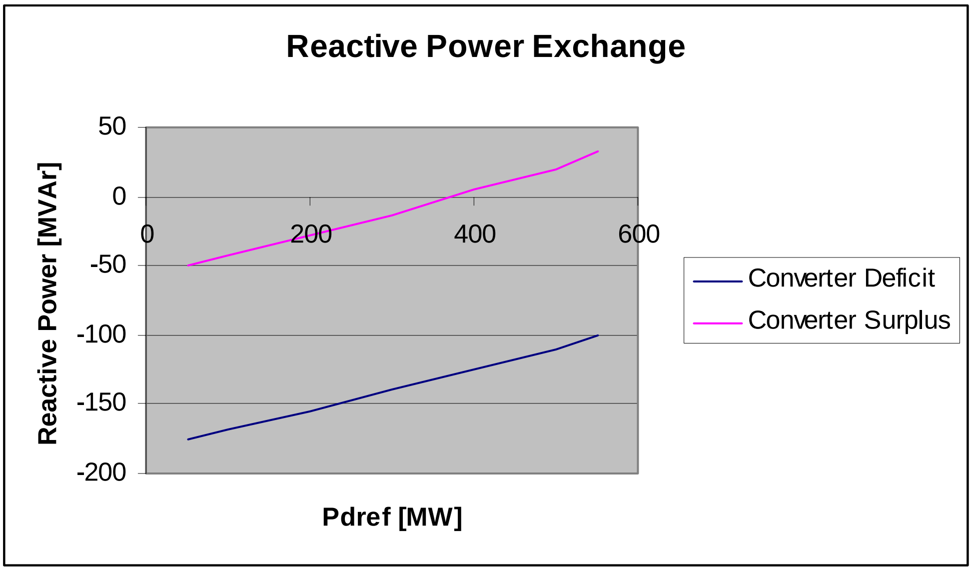


Figure (4) Reactive Power Exchange Limits

3.2 Valves and Valve Hall

The valve hall is about 13.0 m high and under normal operation is ventilated with slight overpressure to prevent dust ingress. The valves are all of suspended type arranged in two rows, one for each side. The smoothing reactors located on the d.c. neutral side are located just outside the valve hall and are connected to the mid-point of the South side valves through wall bushings, which contain also the DCCT's for the converter protection.

With this arrangement the d.c. side voltages is as follows:

- Line to neutral (across 12 pulse bridge) 176 kV
- Line to ground 88kV

Each valve unit consists of 6 thyristor modules connected in series, with 6 thyristor levels per module. The thyristor level contains a 5 inch. dia thyristor (type YST 90), voltage grading circuits and a Thyristor Control Unit. The valve arresters are mounted at the side of the single valve inside the valve hall.

The valve cooling system used here is a single circuit system using only de-mineralised water with heat exchangers (dry coolers) located outside. This system is relatively easy to maintain and avoids the hassles of large outdoor cooling towers.

The smoothing reactors are of air insulated type and have a rating of 30 mH each.

3.3 Converter Transformers

The converter transformers are of single-phase 3 winding type and have the following main parameters:

- Capacity 201 MVA per single phase unit
- Voltage 400/· 3 kV rms, 74.5/· 3(Y) rms,/74.5 kV (÷) rms
- Cooling OFAF

The tap changers, two per unit, are located within the main tank. All the bushings except the 400 kV high voltage bushings are inside the valve hall. Accordingly the star and delta connections for the transformer secondary to interconnect to the two 6 pulse bridges are located within the valve hall. Six of the total seven converter transformers have been manufactured in ABB's works in Baroda in India.

Figure 5 gives an overview of the HVDC Station at Vizag as seen from the South side.

Figure 5.0 View of Second 1 x 500 MW HVDC Block from South Side

4.0 CONTROL & PROTECTION SYSTEM OVERVIEW

4.1 HVDC Control System – Basic Control Modes

The normally used control mode is the constant power control mode for power flow in either direction. This is also the control mode where the higher order controls explained later, add their contributions so as to derive the effective current order which is fed to the Converter Firing Control. The reference point for the power order is the AC main bus bars on the inverter side.

In addition to this constant current control mode is also provided. This is a specific control mode used for limited purposes like testing current rating of main circuit equipment.

4.2 Higher Level Controls

Two higher level controls contribute to the normal power control mode depending on the system configuration and network behaviour.

4.2.1 Power Modulation (AC System Stabilisation control)

This controller provides a contribution to the set power order so that the HVDC power can be modulated so as to damp post disturbance power oscillations in either network. When disturbance occurs in either the Southern or the Eastern regions and power oscillations set in, the power modulator in the d.c. provides variation of d.c. power to stabilize the affected a.c. network. The undisturbed a.c. network is used as a reference (or bulwark) while damping of oscillations is attempted on the disturbed network. The contribution from the modulator will be stopped if, in the course of modulation, the disturbances get transferred to the other network

4.2.2 Frequency Control

The frequency controller which is active always, essentially helps maintain the network frequency, on either side, within a dead-band (+/- 0.5 Hz), about a target frequency F_{TR} (settable between 47.5 & 51.5 Hz), provided the network on the other side is operating within a specified dead-band (0.05 Hz of it's pre-set frequency). The frequency controller contribution is stopped if during it's action, the reference network frequency goes out side it's set band.

4.3 Operation in Co-ordination with Block-1

Both the blocks of 500 MW are envisaged to operate in parallel but independently. As joint operation mode is not provided for currently, essential control co-ordination like for example, operating mode for the RPC is coordinated manually by the respective station operators. During the detailed design phase of Block-2 it was decided to locate the control mimic in the Block-1 control room itself to enable easy coordination of the control modes by the station operators.

Another aspect of coordinated control of both the blocks involves proper response of the power modulation control and frequency control during system disturbances. In order to fulfill this, detailed system studies were done by modelling the control functions proposed for Block-2 with broad based models of similar type being assumed for Block-1. These studies included load flows over the full operating range at the given system voltage limits and dynamic simulation studies involving simulation of single phase to ground and three phase faults followed by tripping of lines and filters as appropriate, as would be done by the RPC controller or over-voltage limitation function in the RPC. The slope settings for the frequency controllers were chosen similar for both the blocks to avoid conflict.

For the Southern side which is much stronger there is little problem in individual or combined operation of both the blocks as far as control of overvoltages are concerned or for post fault recovery. For disturbances in the Eastern region some special measures are required to be taken particularly when the series compensation on the Jeypore lines are in service.

4.4 Protection System

The HVDC station at Vizag uses all the conventional protections normally employed in such schemes. The entire protection system is digital and built around ABB's MACH-2 platform. The protections can be broadly classified into the following areas:

- AC side protections including the converter transformers
- AC Filter protections
- DC side protections covering all equipment including valves

All the station protections including the bus-bar protections and the converter transformer protections are all covered through digital protections within Mach-2. The converter transformer is mainly covered by differential, over current and over-excitation protections apart from the standard Buchholz relay. The switchyard has AC over-voltage and bus differential protections.

A.C. filters are provided with capacitor bank unbalance, earth-fault and resistor/reactor overload protections. The filter low voltage tuned circuits are also covered by a supervision for de-tuning, which monitors for any high currents within the parallel LC circuits.

The d.c. side protections include the following:

- Converter Protections
    - Voltage Stress which is also linked to the Converter transformer tap changer control
    - High Angle Supervision
    - DC Overcurrent
    - Low voltage detection
    - Thyristor Monitoring
    - Valve Misfire Protection
    - Cooling Water Temperature Supervision
- Pole Protections
    - DC over voltage & under voltage protections
    - DC Harmonic protection
    - DC differential

- Smoothing reactor and earth-fault

5.0 SYSTEM TESTS

5.1 Sub-system and H.V. energisation tests

For the Vizag-2 HVDC project almost all the control and protections systems are micro-processor based. Most of the sub-system software testing was therefore performed during the factory system tests at Ludvika, Sweden. The cubicles for control and protection and operator communication were interconnected to each other and to the HVDC simulator which represented the main circuits. The system tests performed at site were in many cases a repetition of the tests performed in factory with actual main circuits connected to the real AC and DC systems.

Prior to the system tests the site verfications involved a step-by-step procedure consisting of sub-system tests to check interconnected equipment prior to High Voltage energisation and the H.V. energisation tests to check for corona, abnormal noise and any other abnormalities prior to commencing power flow.

5.2 System Tests

The system tests were the final tests where everything works together: controls, main circuit equipment, filters and other supporting systems connected to the a.c. networks under the supervision of the test team and the system dispatchers. The basic system tests involved start/stop and ramping up of the block in power and current control, verification of filter switching, low and high power tests in both directions, stable converter control mode shift, change over to redundant control systems, thyristor monitoring, protective block sequences, emergency trip, auxiliary power disturbances and verification of tap-changer and reactive power controls.

The co-ordinated efforts together with the regional load despatch centers made it possible to perform the system testing in only six weeks from de-blocking to successful trial operation. Having the original test plan in consideration, when discussing a suitable detailed test program, the final schedules were decided on day-to-day basis. Example of tests performed are current and power control and emergency power control, frequency control, sub-synchronous damping control and supervision, and heat run with thermovision check. Tests were carried out in both power directions with and without the adjacent converter in operation.

In addition, tests were performed to provoke interactions between the two independent 500 MW converter blocks. It was shown that pre-insertion resistors on the converter breakers reduce disturbances when energizing converter transformers adjacent to the operating converter. The East system is relatively weak at the point of the converters location and it was also shown that the both converters' active and reactive power controls need to be coordinated by the operators in order to reduce the fluctuations of the East converter bus voltage.

5.2.1 Tests of Sub-Synchronous Damping Controller

A sub-synchronous resonance damping controller has been provided in the Vizag-2 HVDC system to provide positive damping in case of build up of sub-synchronous torsional interactions, particularly on the nearby Simhadri thermal machines. The Simhadri plant has 2 x 500 MW machines which could be subject to some sub-synchronous oscillations during any disturbances, which could be further negatively damped when Vizag-South side is the rectifier and under conditions of weak South side a.c. network.

Accordingly it was decided to subject the installed controller to some basic checks, if not the full scale tests. During the course of system tests an opportunity arose whereby the two 400 kV circuits to Khammam were to be tripped for a planned shutdown while the connection to Vijayawada was minimal. This was also the condition wherein power flow was from South to East, thus fulfilling the criteria of South side being the rectifier side.

The tripping of the Khammam line itself became the disturbing input and the output of the Sub-Synchronous damping controller was monitored to check for positive damping, under the post tripping weak network condition. The torsional frequency of interest (19.9 Hz) was monitored during this phase, which showed proper damping.

5.2.2 Ferro-resonance

Detailed system simulations showed a risk of ferro-resonance on the East side at certain system conditions with the series compensation in service at Jeypore. This condition occurs only when power flows from the South to the East side which is not the normal direction of power flow.

Bypassing the series compensation would cease the ferro-resonance. Hence, a ferro-resonance detection circuit was developed and supplied on the East side. The principle of the detection circuit is that it monitors a characteristic harmonic that occurs during ferro-resonance. Should the harmonic level breach the threshold setting values, a signal is released. The signal from the detecting circuit can be transmitted to Jeypore by teleprotection in order to by-pass the series capacitors and interrupt the resonant circuit.

6.0 CONCLUSION

The new 400 kV transmission lines and the second converter block associated with phase two went into service in January this year, 2005. The full phase two started commercial operation in March following extensive system tests.

The project was handed over well before the scheduled period to the Owner, M./s. Powergrid. One major feature of this project has been the quantum of indigenisation in the products used. Apart from the majority of the convertor transformers and all the capacitors, the main bay 400 kV circuit breakers, all bay instrument transformers and disconnectors were supplied locally. Some of the system studies for the higher level controls were also performed locally.

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