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Analysis of Fault Occurrences on HVDC Stations- A Case Study of Chandrapur-Padaghe HVDC Link

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Abstract

In this case study I tried to understand various stages of power transmission from Chandrapur generating power plant to Padaghe receiving station including need of HVDC line in place of EHVAC in Chandrapur-Padaghe line, its commissioning, erection, financing, various problems faced by MSEB engineers during commissioning of line and during operations. This case study also contains few critical issues and faults on line and frequently occurring fault also. During this case study I have suggested some corrective actions to MSEB engineers of Padaghe station to improve reliability of plant and prevent frequently occurred fault in plant and on line.

Introduction

A high-voltage direct current (HVDC) electric power transmission system uses direct current for the bulk transmission of electrical power, in compare with the more usual alternating current (AC) systems. For long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. For underwater power cables, HVDC avoids the heavy currents required to charge and discharge the cable capacitance each cycle. For shorter distances, the higher cost of DC to AC inverter equipment compared to an AC system may still be authorized; due to other benefits of direct current links. HVDC allows power transmission between unsynchronized AC transmission systems. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz. This improves the stability and economy of each grid, by allowing exchange of power between incompatible networks. It has number of advantages as compared to EHVAC system which we will discuss later. Now a day's HVDC is growing rapidly as compared to EHVAC transmission system in India and all over. In this case study I tried to understand various stages of power transmission from Chandrapur generating power plant to Padaghe receiving station including need of HVDC line in place of EHVAC in Chandrapur-Padaghe line, its commissioning, erection, financing, various problems faced by MSEB engineers during commissioning of line and during operations. This case study also contains few critical issues and faults on line and frequently occurring fault also. During this case study I have suggested some corrective actions to MSEB engineers of Padaghe station to improve reliability of plant and prevent frequently occurred fault in plant and on line.

Introduction of Chandrapur-Padaghe HVDC Link

The Chandrapur–Padghe HVDC transmission system is an HVDC connection between Chandrapur and Padghe (closely Mumbai) in the state of Maharashtra in India, which was put into service in 1999. Figs 3.1 explain real view of Chandrapur generating plant. It interconnects the coal-fired Chandrapur Super Thermal Power Station to the greater load centre of Mumbai. The project has a 752 kilometers (467 miles) extended bipolar overhead line. The transmission voltage is ± 500 KV & the greatest transmission power is 1,500 megawatts. The project uses thyristor valves, arranged in a single twelve pulse bridge per pole. The project was constructed by ABB and BHEL, and is owned by Maharashtra State Electricity Board (MSEB). The Chandrapur converter station is situated 20 kilometers (12 miles) from the Chandrapur back to back HVDC station. The close proximity of the two converter stations meant that the control systems required to be carefully coordinated, a work made more challenging by the fact that the two stations were constructed by separate manufacturers. To address this problem a series of joint simulation studies, involving the control equipment from both converter stations joined to a common simulator, was execute.

Need of HVDC Line from Chandrapur to Padaghe

The power demand in the state of Maharashtra is concentrated in Western part around Mumbai, Pune and Nasik regions, where as greater thermal power generation is concentrated in the eastern part of the state due to riches of coal stock in the area. The existing generation of CSTPS is 2340 MW and central sector share around 1000 MW is also delivered at Chandrapur bus. The existing transmission network involve of three 400KV circuits between Chandrapur and Mumbai can safely transmit 1200 MW without examine any contingency outages; it was therefore necessity to supply additional transmission capacity of around 1500MW between Chandrapur and Mumbai. Expansion of 400KV transmission network by build several 400 KV lines were not practicable due to constraints of right way. Therefore the other two choices like erection of 800 KV AC link or HVDC bipolar link were under erection. HVDC bipolar link was found to be better choice, long term requirement and anticipated support to system stability.

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 systems 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 MVAr. There are two DC filter branches per pole and per station.

Harmonic Problem on Line

Harmonic voltages and current in an electric power system are a result of non-linear electric loads. Harmonic frequencies in power grid are a frequent cause of power quality problems. Harmonic in power system result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsation in motors. Reduction of harmonic is considered desirable.

Harmonic Fundamentals

Harmonic provides a mathematical analysis of distortion to a current or voltage waveform. Based on fourier series, harmonic can describe any periodic wave as summation of simple sinusoidal waves which are integer multiples of the fundamental frequencies. Harmonic are steady state distortions to current and voltage waves and repeat every cycle. They are different from transient distortions to power systems such as spikes, dips and impulses.

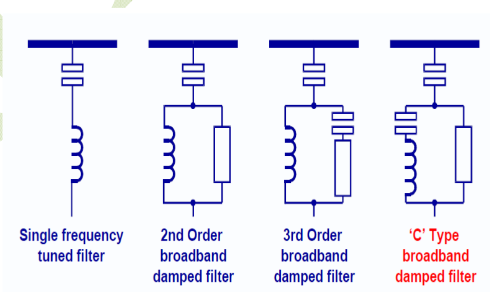

Fig 1.1 Types of filters

For Proper load sharing with better efficiency necessitated to enhance the loadability of the link either by establishing new circuit or by installing series compensation. Being the most feasible techno-economic solution, series compensation has been provided on both the circuits of Chandrapur - Padaghe link to enhance theinter regional power transfer capacity along with dynamic control on inter area power oscillations ensuring system stability. Apart from having an edge on account of better technical suitability, expenditure for installing series compensation was also much below the expenditure required for constructing a new line, besides avoiding huge detrimental impact on environment. The series compensation comprises of two parts i.e., Fixed Series Compensation & Thyristor Controlled Series Compensation as described below,

- Fixed Series Compensation (FSC)
- Thyristor Controlled Series Compensation (TCSC)

Suggestion for Filter Bank Connection


Fig 1.2 Filter capacitor bank without Lug   Fig 1.3 Filter capacitor bank with Lug

Abnormal Condition:

During my visit to the plant and switchyard I saw people directly connect filter banks in series with each other which is shown in fig. 1.2. Due to direct contact of link between two banks in case of high voltage surges because of heat and high temperature the link gets heated and damaged which results into break in operation of filters.

Suggestion:

After understanding above frequently occurring problem I suggest to MSEB engineers to use the lug to link which connects two filter banks. Fig. 1.3 describe here when two banks connected by link which lugged properly the link is more tightly connected to the nut-bolt of insulator so that the reliability and quality of supply will enhanced.

Result:

Due to properly lugged cable even in case of high temperature the lug and nut-bolt not get loosed and link will not get damaged.

Suggestion to Reduce Bird Fault

Fig. 1.4 Bird fault frequently occurs on this filter banks

Abnormal Condition: As shown in above figure these filter banks frequently facing bird fault which causes due to bird gets come in contact with two links of bank. Due to which surges are introducing in line and bank get tripped which results into increasing the harmonic distortion of line.

Suggestion:
After analyzing the occurrences of bird fault, I suggest MSEB engineers that if we provide metal cage of plastic or rubber coating around the filter banks, bird will not come in contact with bank so that system will not face abnormal condition and supply reliability will be stable.

Few Suggestions to Reduce Failure

I have suggestions which may help to reduce failures which occur because of various causes,

Improved design and manufacturing practice: By adopting CAD and better shop floor management, more reliable units could be manufactured to eliminate:

- Poor short circuit withstand capability
- Manufacturing defects including cooling system
- Problems associated with bushings
- OLTC including selector/diverter switch
- Tertiary winding failure wherever provided improved testing method
- Transformer should be simulated to actual service condition first by sequential testing and then passing necessary current which could result into temperature rise. Thereafter conduction of all high voltage application tests could bring out insulation weakness.
- Simulated short circuit test if necessary on scaled model and measurement of magnetic balance and magnetization current could reveal abnormality.
- Finally oil parameter could be recorded after completion of all the tests and compared with initial values.

Few problems which frequently occurs on transmission line and HVDC switchyard with remedial steps

Chandrapur V.C. system tripped due to auto change-over scheme failed: Auto change-over schemes resistance get damaged due to which change-over scheme get faulty, Damaged resistance replaced and made system healthy.

PLCC capacitor bank burned at Chandrapur terminal: Capacitor bank temperature was tremendous due to overheat bank get damaged, replaced capacitor bank with new one and made provision of fan for better cooling to capacitor bank.

AC filter Z1+Z2 tripped at Chandrapur: Filter Capacitor bank connection loosed and due to excessive heat it get damaged and filter gets damaged, replaced Capacitor bank and make connections of Capacitor bank through lugs.

Pole-II tripped: Due to unequal tap changer position of Y-phase converter transformer at Chandrapur Terminal, tap position of transformer converter transformer changed.

Sparking at DC line isolator at Chandrapur: Isolator not fitted exactly at appropriate place due to which high heat and sparking occurred.

S1-P1.Z11 filter tripped on bird fault: Fault checked and reset filter bank.

Line fault due to lightning: Line charged again and faulty lightning arrestor replaced.

AC overvoltage trip due to 400KV bus fault at Padaghe: Due to ground to fault AC line tripped, fault cleared and system restored.

Sparking on B-Ph a bushing of converter transformer at Padaghe: Bushing connection gets loosed, tighten bushing connection and fault corrected.

Bus fault at 400 KV Substation Padaghe pole tripped on commutation failure: Commutation problem corrected in thyristor bank and charge bus again.

Some Operational Experiences on Chandrapur-Padaghe Bipole Line

Degradation of Light Guides

The thyristor valves are installed in controlled atmosphere and the contractor's designs need system. The light guide were laid in straighten channel and branched out at module place for connection to thyristor valve. The light guides are supported at the different locations by fore way finger bracket fixed to channel carrying the light guides.
Following incidences took position in pole-II at Chandrapur.

- In 2ndOctober 1999, the reception of indicating pulse stopped activity.
- In June 2000, protective firing for large no. of thyristors was register by control system.
- In September 2000, again protective firing for large no. of thyristors recorded by control system.

Recommendation and implementation

Based on the relationship of various parameters and subsequent conclusion in the laboratory studies as explained above, following recommendation given by ABB for improvement.

1. The maximum permissible limit of %RH setting of 6% has been changed to 50% during operations.
2. Curved light guide channels have been installed in place of straight line guide channels to increase creep age distance.
3. Existing fine air filters are replaced by EU9 filters (Absolute filters)
4. The air inlet is made further tight to ensure that incoming air pass through the filter only.
5. Fresh air intake is minimized and setting over the pressure in the valve hall is also reduced.

After all implementation of the above recommendations in the year 2001, the light guide channels are regularly checked during annual outage and so far there is no damaged to the light guides are found.

Failure of Converter Transformer

The converter transformer are single phase three winding units of 298.6 MVA capacity each and having line winding of 400/1.73 KV and delta and star connected valve windings of 211 and 211/1.73KV voltage rating respectively. Transformers are designed by ABB Sweden. Out of total 14 transformers M/s. BHEL India manufactured 8 numbers and 6 are accommodating by M/s ABB Sweden.
The failure was analyzed examine the following,

1. Frequent and high amplitude transients.
2. Failure occurred in normal operation; however no direct external reason for the breakdown was recognized.
3. Turn to turn breakdown in star winding.

4. No breakdown paths to ground in the transformer.

As the part of investigation of failure of the converter transformers, activities were divided into three parts namely;

1. Permanent changes in the protection system
2. Site measurement i.e. survey of operating parameters
3. Operational limitations.

Permanent changes in the protection system

It was agreed to implement the following changes as the precautionary measure to avoid aggravation of failure of converter transformers.

1. In commutation failure protection, commutation failure counter reset time has been changed from 1 second to 30 minute. Acceptable 12 pulse commutation failure has been changed from 15 to 5. Hence within 30 minutes if 5th commutation failure occurs the system will trip and avoid the further stresses.
2. In DC line protection, restart attempt counter reset time has been changed from 30 seconds to 1 hour. Restart attempt for normal voltage has been changed from 2 to 1 and for reduced voltage it has been removed. On occurring of line fault the system will go into reduced voltage mode. If again line fault will occur within one hour the system will trip, reducing the further stressed on the system.

Failure of DC neutral cable: The neutral of the rectifier bridge is brought out in the DC switchyard through underground three nos. aluminium 25 KV DC XLPE insulated cable connected in parallel. In the year 2003 the DC pole tripped on neutral Bus DC differential protection. From the transient fault recorder graphs it was analyzed that the DC neutral current amplitude is decreasing prior fault. This indicated that there must have some leakage path for this current. There were only two possibilities for this, either due to failure of the surge arrester connected to the neutral side of the cable itself. After measurement of the insulation resistance, it was found that one of the cables is showing very poor results as compared to others. The cable was tested for high voltage and it was found that there was a hole in the insulation through which the current was getting leaked. The aluminum cable is having an Impulse level of 375 KV while the equipments connected on the neutral bus are having a Impulse level more than 375 KV. During earth fault on DC side maximum stresses on the neutral. Since the impulse level of the cable was less as compared to the equipment connected to neutral bus, the cable sustained the maximum stresses during faults. These cable have been replaced by XLPE copper cables having impulse voltage 550 KV replaced the old cable for both the poles. After replacement of cables no leakage current has been notice.

Snapping of earth wire on DC line: Through the whole span of the DC line the OPGV is proceed over the other pole AAAC (All Aluminium Alloy Conductor) ground wire is used.
The first occurrence of snapping of 80 mm2 AAAC ground wire took place on the 15th November 1998 (Before commissioning of the line). Therefore repetition snapping has been noticed at no of event. After inspections it was noticed majority of snapping s were at the tip of fixing point of the vibration damper supplied by M/s EMI Transmission Ltd. M/s EMI and M/s MML supplied 50% each of the total quantity. The chemical analysis, mechanical tests revealed that there is no problem with the 80 mm2AAA conductor. Matter was suggested to Central Power Research Institute (CPRI), Bangalore India for investigation. After test on ground wire and vibration damper, CPRI opined that the design of Ms EMI make vibration damper is defective. Therefore Ms EMI changed all the vibration dampers supplied by them by the end February 2001. After substitute of EMI make vibration damper in February 2001 the breakdown due to snapping of earth wire were reduced. From February 2001 to May 2003, 20 numbers of occurrences were observed at the spot where the MML make vibration damper was used. This occurs particularly from January to May every year. As per the testing report this happen especially from January to May every year. As per the testing report of CPRI Bangalore, AAAC earth wire is very sensitive to notches, which speed up the fatigue failure, more in case of high wind velocity. The following result is drawn from the snapping of AAAC ground wire. The basic material of AAAC is soft in the nature and does not have adequate ultimate tensile strength to withstand the tension at higher line spans. The cutting of strands on AAAC wire starts at hardware as well as on the fixing

points of dampers. This gradually aggravates during swinging of wire under high wind condition and results in snapping of wire after the duration of 2-3 years.
It was therefore decided to replace the total AAAC ground wire by 7/3.66 GI wire. Till August 2008, 100% of AAAC earth wire has been rep laced by 7/3.66 GI wire. GI wire has a better strength and arrest the problem of frequent snapping of earth wire has been totally arrested.

Flash over due to environment on DC line: Out of entire 752 Km DC line, a small spread of length of around 4 Km (Location no 1792 to 1809) passes over hilly area of Naneghat. During the month of May 203, the line used to go into the Reduced Voltage mode often. The line patrolling did not show any apparent faults on DC line as well as insulators. The site was visited during early morning and it was observed that the entire towers are absorbed in low-lying clouds at top of the hill. Heavy hearable noise was heard momentarily. However no flashovers were seen, but during darkness time, heavy flash over were seen followed by loud chattering noise. The polluted insulator on all the towers (Mainly dust pollution0 were washed by de-ionized water and silicon grease was applied on the insulators. Afterwards there were no flashovers due to this line did not go to decreased voltage mode again. There is no more location at about 5 Kms. Away from a Sugar factory near Rahuri where similar activity took place. The problem was corrected above.

Problems with electrode: station Earth electrode was in used for quite long duration during outage on poles because of transformer failure. The ground electrode at Chincholi (Chandrapur) was found to have suffered electrolytic corrosion and one of sections was replaced. However at Anjur (Padaghe) the cable insulation was deteriorate due to extreme heating. The cables are now laid in trenches and are reinforced. The electrode station had otherwise no problems.

Failure of Snubber circuit capacitors: The function of the Snubber Circuits (Voltage Divider Circuits) is to give even voltage distribution among the thyristors at all frequencies. As per diagram below three separate dividers are connected across the thyristors.

i. R1C1-branch is damping the commutation overvoltage and reduces the voltage unevenness due to scatter in thyristor recovery charge.
ii. R3C3-branch is main origin for charging the TCU (Thyristor Control Unit)
iii. R4-branch is a direct voltage divider.

From the January 2008 to June 2008 the Chandrapur-Padaghe link (Pole 1/Pole 2) has failed 10 times due to failure of Snubber Circuit capacitors. After every occurrence the corresponding place were investigate. And in the most cases the capacitor CX1 found either burst or with their capacitances very much deviated from the admissible once. Due to explosion of the capacitors, also got burnt and spoiled the light guides. The occurrences were discussed with the M/s. ABB Sweden. The experts from ABB attend Chandrapur as well as Padaghe terminal station and investigate few of the thyristor modules. As a part of investigation all the capacitors in Pole 1 was measured. From the statistical data of measured values 84 nos. out of C1X capacitors and 31 nos. out of 1152 nos. of C3 capacitors were found beyond the admissible limit. Also on around 60% of entire capacitor terminals in the form of black spot were noticed. The examination was conduct by AMM. Investigation report says that the capacitors have developed minor leaks around the top sealing, allowing the insulating oil to absorb moisture from the air. The increased moisture level of the oil and some loss of the insulating capability have reason accelerated ageing of the capacitors. The voltage withstands capacity of the capacitors has been lower leading to degradation and in some cases destruction.

Operational Performance

Despite of different failures/problems incorporated above, the HVDC system had helped to outlast the associated grid at two severe events:

i. During the year 2003 in the month of December 2003 the complete WREB system was disturbed due to heavy power swing in the Western Network of the Maharashtra state. The islanding mode of the HVDC system got enabled and helped to survive the grid for 18 minutes.
ii. On 28th of February 2005 due to fire occurrence and KTPS grid control room, the generation and outgoing lines were wholly affected. During this occurrences all parallel AC lines from Chandrapur towards Western

part of Maharashtra were tripped on power swing and the HVDC poles got islanded along with generators and survived the Eastern and Western grid of MSETCL.

iii. During transient fault in the parallel AC lines the damping controller always gets activated and stabilizes the network.

iv. During year Feb 2007 there was a system disturbances, all the parallel AC lines were tripped and the VKM-KTRT grid was divide and Islanding mode of HVDC got enabled and survive the MSETCL system from finished collapse

Conclusion

With the trifurcation of MSEB and forming of Maharashtra State Electricity Transmission Company Ltd. HVDC link provided to be a firmness of MSETCL transmission system. Operation of HVDC link embedded with existing HVDC system has fulfilled commitment of better grid stability, reliability and also decrease in transmission losses etc. From commissioning up to now MSETCL has been done several changes and improvements in the system to avoid abnormalities in the line and plant and to supply trustworthy service to the consumer. Various complicated faults which were appearing in past and in recent years are still unsolved. M/s. ABB, M/s. BHEL and MSEDCL together working out on these issues. This was great experience for me to undergo the project work at one of the giant HVDC plant of the country. During my implant training and thesis work there are number of preventive maintenance outages taken by engineers for smoothing operation of the system. I have suggest few suggestions for improve reliability and quality of operation in the plant like connecting lugs to the filter banks instead of direct connecting filter bank to each other. Due to heat this direct connection gets loosed and conductor gets burnt. By using lug conductor not get loosed or damaged. I also suggested providing net to filter bank which will prevent the bird fault which occurs due to bird touches to the filter bank contacts due to which filter bank gets tripped. Due to this Chandrapur-Padaghe 500KV1500MW HVDC line MSEB provides electricity to western Maharashtra with high reliability and with saving huge amount of money.

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