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A CASE STUDY ON FAULT OCCURENCES ON HVDC STATIONS OF VARIACE LINE IN INDIA

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ABSTRACT: In Irrigation canal based Small Hydro plants, utilizing the heads available gives more or less constant power generation. But it is seen that the head available is almost constant whereas there are large variations in the discharge available. The power generation is completely dependent upon irrigation releases season wise through the canal which depends upon the crop pattern in the region. Power generation is for nine months as months of April, May and August are not considered since discharge is less than 1 cumecs. Modeling and simulation of small hydro power plant is valuable tool for planning power plant operations and judging the value of physical improvement by selecting proper system parameters. Earlier this was done for large or small hydro power plants. But for canal type small hydro power plants this study helps in verifying design of windings, costs and safety conditions. It also helps in verifying the parameters of control equipment like water level regulator, governor, exciter etc. and in determining the dynamic forces acting on the system which must be considered in structural analysis of the penstock and their support. In this project, the simulation model of a typical canal type small hydroelectric power plant was developed through interconnection of models of various equipment of the plant under consideration in a MATLAB/Simulink based software environment. The various components of small hydroelectric plant like governor, Semi-Kaplan turbine, synchronous generator, and exciter are being considered under modeling and simulation. The aim is to study its behavior during phase to phase fault. This study helps in verifying costs and safety conditions, in selecting the best alternatives in the early phase of design and to determine the requirements of special protection devices to control over-current and under-voltage.
Keywords: A CASE STUDY ON FAULT OCCURENCES ON HVDC STATIONS.

I. INTRODUCTION

In this case study I tried to pursue a deep study of faults and abnormal conditions on line and main equipments of switchyard and to make a systematic documentation of project commissioning, erection, operation, maintenance and record of various abnormal conditions and fault occurrences on Chandrapur-Padaghe HVDC line. I started my work from introduction of both transmission system which are Extra High Voltage Alternating Current (EHVAC) and High Voltage Direct Current (HVDC). I understand the historic background of High Voltage Direct Current and collect reasons for replacement of High Voltage Direct Current transmission system in place of Extra High Voltage Alternating Current transmission system. I tried to understand the reasons behind replacement of two existing EHVAC transmission lines from Chandrapur to Mumbai by single HVDC transmission line. As we know that in an AC system, voltage conversion is simple.

An AC transformer allows high power levels and high insulation levels within one unit, and has low losses. It is a relatively simple device, which requires little maintenance. Further, a three-phase synchronous generator is superior to a DC generator in every respect. Overall, generation, transmission and distribution of High Voltage Alternating Current is more easy than other aspects. For these reasons, AC technology was introduced at a very early stage in the development of electrical power systems. The operations and maintenance of AC system is relatively simple and less than DC transmission system. Energy conversion process is not required in the EHVAC transmission system. Due to these reasons it was soon accepted as the only feasible technology for generation, transmission and distribution of electrical energy. However, high-voltage AC transmission links have disadvantages, which may compel a change to DC technology.

HVDC transmission system is suddenly taken over to the AC transmission system in last some years. The significance of HVDC is increases due to its various advantages over AC transmission system such as more power transmission, no skin effect, less size of conductor, less stability problem, no corona and radio interference etc. But as the use and demand increases the HVDC systems start to face some challenges like frequently occurrence of various abnormal conditions and critical faults on the line. Due to these various abnormal conditions and critical faults the reliability and quality of energy transmission is reduces. In the interconnected grid when High voltage line like Chandrapur-Padaghe HVDC link get disturbed then whole grid gets affected which results into unreliability in the energy transmission.

In this case study work I tried to compare both EHVAC and HVDC transmission system operationally as well as economically. I tried understand need of new project installation, finance and estimation costing of project. I got information about parameters and rating of basic equipment of HVDC line and switchyard such as convertor transformers, lightning arrestors, smoothing reactors, AC filters, DC filters, HVDC line, HVDC electrode station and electrode line, optical communication etc. on which abnormal conditions are frequently occurs. I tried to grasp the idea of operational modes of line, special features of Chandrapur-Padaghe HVDC line such as Power modulation, Master control location, Line Fault Locator, Loss Optimization etc. I tried to understand basic circuit equipment of energy conversion process, Thyristor Controlled Series Compensation (TCSC) installation to eliminate harmonic distortion etc. I saw function of various testing equipments and kits available at padaghe station which are used for testing purpose. I have made a systematic table for various faults on line and main equipments of switchyards with its effect on line performance and remedial measures.

I have made this fault analysis table from log book of maintenance department in which sequence of various faults with its remedies are mentioned. I discussed various critical and unsolved issues with MSEDCL engineers and tried to reach up to solution of these issues and faults. I also tried to suggest few suggestions to MSEDCL engineers related to designing and maintenance work to reduce failures like connecting a lugged conductor to filter banks in place of direct contact of bare conductor and another suggestion regarding to reduce bird fault which frequently occurs on the filter banks. And they implement one of my suggestions which I have mentioned in this report.

II. HVDC INTRODUTION

A high-voltage direct current (HVDC) electric power transmission system uses direct current for the bulk transmission of electrical power, in comparison 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. Now a day's HVDC is growing rapidly as compared to EHVAC transmission system in India and all over.

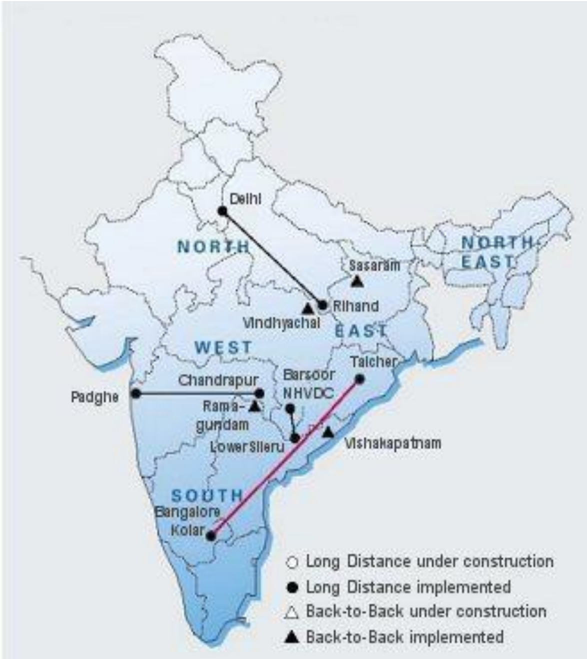


Figure1. India's position in HVDC

Power Transmission was initially move out in the soon 1880 using Direct Current (DC). With the accessibility of transformers (for stepping up the voltage for transmission over extended distances and for stepping down the voltage for secure use), the evolution of strong induction motor (to benefit the users of rotary power), the accessibility of the higher synchronous generator, and the facilities of transform AC to DC when need, AC gradually replaced DC However in 1928, rising out of the introduction of grid control to the mercury vapour rectifier around 1903, electronic devices start to show genuine view for high voltage direct current (HVDC) transmission, because of the efficiency of these devices for rectification and inversion is high. The most important contribution to HVDC came when the Gotland Scheme in Sweden was commissioned in 1954. This was the World's first commercial HVDC transmission system. This was sufficient to transmit 20 MW of power at a voltage of 100 kV and consists of a single 96 km cable with marine return. With the strong evolution of converters (rectifiers and inverters) at higher voltages and larger currents, DC transmission has become a greater factor in the planning of the power transmission. In starting all HVDC project used mercury arc valves, invariably alone phase in erection, in compare to the low voltage multiphase units used for industrial application.

III. COMPARISON OF AC AND DC TRANSMISSION ADVANTAGES OF DC OVER AC

A. More power can be transmitted per conductor per circuit:

The capabilities of power transmission of an AC tie and a DC tie are distinct.

For the same isolation, the direct voltage Vd is equable to the peak value ($\sqrt{2}$ x rms value) of the alternating voltage Vd.

$Vd = \sqrt{2}\ Va$

For the same conductor dimension, the same current can be transmitted with both DC and AC if skin effect is not considered.

Id = Ia

Thus the corresponding power transmission using two conductors with DC and AC are as succeed.

DC power per conductor Pd = Vd Id

AC power per conductor Pa = Va Ia cos Φ

The more power transmission with DC over AC is assumed by the proportion of powers.

Pd/Pa=$\sqrt{2}$ /(COS Φ)=[1.141 at pf=unity
1.768 at pf=0.8]

In usage, AC transmission is carried out using either single circuit or twice circuit 3 phase transmission using 3 or 6 conductors. In such circumstances the above proportion for power must be multiplied by 2/3 or by 4/3.

In common, we are interested in transmit a stated amount of power at a stated insulation level, at a given efficiency of transmission. Thus for the same power transmission, same losses and same peak voltage, we can decide the decrease of conductor cross-section A_d over A_a.

B. Use of Ground Return Possible:

In the case of HVDC transmission, ground return (particularly under water crossing) may be used, as in the case of a monopolar DC tie. Also the single circuit bipolar DC tie is more trustworthy than the correspondent AC tie, as in the occurrence of a abnormal condition on one conductor, the other conductor can go on to act at lower power with ground return. For the same length of transmission, the impedance of the ground path is much less for DC than for the correspondent AC because DC scatter over a much larger width and depth. In fact, in the case of DC the ground path resistance is almost wholly dependent on the ground electrode resistance at the two terminals of the line, rather than on the line length. However it must be endured in mind that ground return has the following drawback. The ground currents result electrolytic corrosion of buried material, interfere with the working of indicators and ships compasses, and can cause hazardous step and touch potentials.

C. Smaller Tower Size:

The DC insulation level for the same power transmission is similar to be less than the corresponding AC level. Also the DC line will only required two conductors whereas three conductors are needed for AC. Thus both electrical and mechanical considerations prescribe a smaller tower.

D. Higher Capacity available for cables:

In comparison to the overhead line, in the cable breakdown appear by puncture and not by outward flashover. Mainly due to the absence of ionic movement, the operation stress of the DC cable insulation may be 3 to 4 times higher than under AC. Also, the absence of continual charging current in a DC cable allows higher active power transfer, particularly over extended lengths. (Charging current of the order of 6 A/Km for 132 KV). Critical length at 132 KV ≈ 80 Km for AC cable. Beyond the critical length no power can be transmitted without series compensation in AC lines. Thus derating which is need in AC cables, thus does not limit the length of transmission in DC. A comparison made between DC and AC for the transmission of around 1550 MVA is as follows. Six number AC 275 KV cables, in two assemblies of 3 cables in flat shaping, need a entire trench width of 5.2 m, whereas for two number DC ±500 KV cables with the same capability need only a trench width of around 0.7 m.

Inherent problems associated with HVDC

Expensive convertors:

Expensive Convertor Stations are need at each termination of a DC transmission link, whereas only transformer stations are need in an AC link.

Reactive power requirement:

Convertors need much reactive power, both in rectification as well as in inversion. At each convertor the reactive power used up may be as much at 50% of the active power rating of the DC tie. The reactive power demand is partly provide by the filter capacitance and partly by synchronous or static capacitors that required to be installed for the use.

Generation of harmonics:

Convertors produce a lot of harmonics both on the DC side and on the AC side. Filters are used on the AC side to decrease the amount of harmonics transferred to the AC system. On the DC system, smoothing reactors are provided. These components add to the expense of the convertor.

Difficulty of circuit breaking:

Due to the absence of a natural current zero with DC; circuit breaking is difficult. This is not a greater problem in individual HVDC link systems, as circuit breaking can be completed by a very fast absorbing of the energy back into the AC system. (The blocking act of thyristors is faster than the work of mechanical circuit breakers). However the lack of HVDC circuit breakers hampers multi-terminal operation.

Difficulty of voltage transformation:

Power is commonly used at low voltage, but for reasons of efficiency must be transmitted at high voltage. The absence of the equal of DC transformers makes it necessary for voltage transformation to carried out on the AC side of the system and stop a purely DC system being used.

Difficulty of high power generation:

Due to the problems of commutation with DC machines, voltage, speed and size are limited. Thus as compare to DC lower power can be generated.

Absence of overload capacity:

Convertors have less overload capacity unlike transformers.

IV. FEW FREQUENTLY OCCURRING PROBLEMS ON TRANSMISSION LINE AND HVDC SWITCHYARD WITH REMEDIAL STEPS:

A. HVDC Line 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.

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

C. AC filter Z1+Z2 tripped at HVDC Station:
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.

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

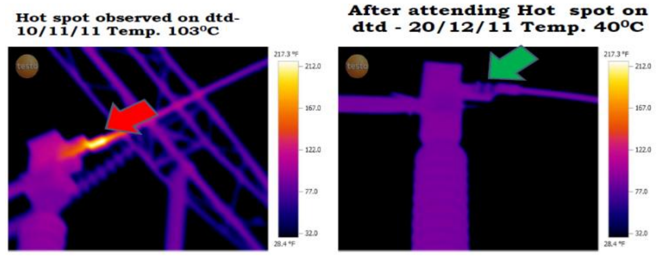
E. Sparking at DC line isolator at HVDC Station:
Isolator not fitted exactly at appropriate place due to which high heat and sparking occurred.

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

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

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

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



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

V. 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 nos. and 6 nos. are manufactured by M/s ABB Sweden.
After bipolar function for a few months, failures of converter transformers at Chandrapur and Padaghe, which are unmatched in nature begin from June 2001. From June 2001 to June 2005, eight transformers have fault. Out of eight failed transformers three numbers are of BHEL India make, and five transformers are ABB Sweden make out of these faulty transformers, one transformer each of BHEL and ABB make, which has failed was repaired earlier. In all the cases transformers connected to star winding have failed.
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.

- 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.
- 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.

Site Measurement:
The survey of operating parameters to be carried out to check any deviation from those specified.
Operational Limitations:
As far as possible, following operating modes to be avoided

- Use of “Increased Reactive Power Consumption” function.
- Manually set “Reduced Voltage Operation”
- “Reduced Voltage Operation” set by protective action. If DC line is not withstanding operation at 500KV DC and automatically enter reduced voltage mode, the power can be reduced in controlled manner and pole be blocked. After clearing DC line problem, the pole can be restarted.

To avoid reflection of disturbance from associated AC DC network, following precaution were to be taken:

- Avoiding manual re-closing of tripped AC line without ensuring that fault is cleared.
- To carry out the maintenance of insulators of DC line wherever repeated failure occur.

To reach to the root cause of failure of converter transformer, all the above said changes have been implemented and strictly adhered to. The intension was not to put the restriction on operation but to enhance the availability of the link for operation under the close supervision to avoid the further damage to the equipment which may otherwise would have caused disruption in the power transmission.

It was in the interest of the both, the HVDC contractors and the organization. A survey of operating parameter was conducted by ABB and it was observed that failure of the transformer seemed to be occurring randomly and the transformer behaves as if they have constant but high failure rate.

Investigation:

The design was scrutinized by design tools. The strength of insulation against repetitive transient was also verified and concluded that no design deficiency is causing the breakdown.

Copper sulphide deposit:

Inspection of winding then disassembled turn by turn shows that, at some locations there

was a shiny deposit on the spacers and conductor insulations. These deposit were identified as Copper Sulphide (Cu_2S)

Influence on Dielectric Strength:

The electric conductivity of CU2S is significantly higher than the conductivity of paper and oil. This means that the presence of CU2S may change the electric field distribution.

The series of the test were performed on both CU2S contaminated material and unaffected material. The result of this test was shows that:

- Partial discharge (PD) initial voltage and the breakdown voltage of the CU2S coated material are significantly reduced as compared to the uncoated material.
- Uncoated and unaffected insulation has the same strength as brand new insulation.

Impact of Transient:

CU2S lowers the D initiation level. Deposition of copper sulphide on the winding alone is not sufficient to create a short circuit or partial discharge between two turns. For either ofthese two happens the insulation has to be further degraded by frequent repetitive transients. During line fault very high stress on turn to turn insulation occurs.

Formation of Copper Sulphide (CU2S):

The transformer oil is basically highly refined mineral oil and consists of mainly mixture of hydrocarbon and other compounds containing oxygen, nitrogen and Sulpher. Most of the compounds containing sulpher can react as with copper under extreme conditions and from copper sulphide deposit.

Conclusion

After investigation ABB reach at final result as:

- Aggressive oil produces copper sulphide
- Copper sulphide weakens the insulation
- Transients arising due to α-900^o operation or transient from continuous higher MVAR operation is adequate to partial discharges. Repetitive transients further reduce the insulation.
- A partial discharge in enough degraded insulation will not destroy.
- When the insulation is enough degraded, PD will continue at normal service voltage level.
- A PD leads to turn to turn fault and transformer breakdown.

Finally transformer oil has been recognized as a culprit of the failure. Further ABB have suggested to use the Nytro 10X oil instead of Naphtha based oil and to add passivator called irgamet-39 in the transformer oil as 1KG/1Kl of oil.

After this final determination and adopting recommendations bipolar operations started on 24th may 2004. But on 14th June 2005 the ABB make repaired transformer in which all suggestions were accepted has failed with inter turn short. Now ABB/BHEL have the further investigate the reason for this failure.

Presently all ABB make transformers and one BHEL make are filled with Nytro 10X oil as suggested by ABB with metal passivator. However BHEL make transformers are still contained with old Naptha base oil with passivator added.

VI. 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. This was great experience for me to undergo the project work at one of the giant HVDC plant of the country. During my in plant training and thesis work there were a number of preventive maintenance outages taken by engineers for smoothing operation of the system. I have also given few suggestions for improving 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 loosened and conductor gets burnt. By using connecting lugs conductor not get loosened or damaged. I have also suggested to provide net to filter bank which will prevent the bird fault which occurs due to bird coming in contact with the filter bank 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 thereby yielding huge monetary savings.

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