

Research and simulation of line overvoltage in HVDC transmission system

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Abstract. The distribution of heavy load area and resource area is seriously unbalanced in China. HVDC transmission system project with long-distance and large capacity transmission characteristics has practical significance in today’s social development. Firstly, this paper discusses the basic knowledge of over-voltage in DC transmission system and analyzes the formation mechanism of internal overvoltage, and enumerates and analyzes the common overvoltage faults at AC side and DC side. Secondly, the electromagnetic simulation software PSCAD/EMTDC is selected to build the model, and CIGRE HVDC standard control model strategy is adopted in each module. Finally, the simulation analysis is carried out, mainly aiming at the AC bus grounding fault of converter station, and the overvoltage waveform under fault condition is recorded. The over-voltage characteristics of rectifier side and inverter side under AC bus fault of converter station are compared and analyzed, which provides reliable suggestions for overvoltage and insulation coordination in future design projects.

1. Introduction
Up to now, a large number of achievements have been made in the research of overvoltage and insulation coordination, which is an important index in DC system at home and abroad. Among them, CIGRE and other institutions put forward a series of hard limit indexes and requirements on Overvoltage and insulation coordination of HVDC transmission system, which are used to standardize standards and facilitate academic exchanges between countries. As early as 1970, some foreign scientific research institutions conducted in-depth research on the environmental deterrent and insulation characteristics of high voltage DC projects, and the research on insulation coordination has always been a key topic.

In the era of underdeveloped material level and science and technology, most of the preliminary research is carried out by physical means, such as field measurement, approximate simulation of DC transmission equipment and layout of transient network analysis instruments, etc. computer technology can accurately and perfectly present the components or components in the DC system, and can be completed by connecting all sub components The construction of the overall model[1]. In the digital analog system of computer, it is very convenient to simulate the development mechanism, waveform and amplitude of different types of overvoltage.

With more and more funds and Research on UHVDC transmission technology invested by China's power grid companies and relevant scientific research institutions, great achievements have been made in overvoltage and insulation coordination in China. Reference[2] describes the insulation characteristics of UHVDC transmission lines in China in detail. Based on China's unique climate, geography and other environmental factors, relevant analysis and multi angle comparative
investigation are carried out. It is concluded that pollution, acid rain, icing and high altitude will seriously harm the stable operation characteristics of DC system. Reference [3][4] mainly analyzes the Xiangshang UHVDC transmission project and ±500 kV Yunnan Guangzhou UHVDC transmission project in detail, and summarizes and refines the characteristics of lightning arrester layout scheme for lines and converter stations in DC projects. Reference [5] used PSCAD / EMTDC, EMTP and other professional electromagnetic transient process simulation software to analyze the problems of overvoltage and insulation coordination in DC system in detail, and detailed description and explanation were given in software use and comparative analysis. In reference [16], various faults of DC and AC systems in Tian Guang AC / DC parallel transmission system are studied under three modes of high flow, high flow and low flow.

To sum up, although the Institute of electrical and Electronic Engineers (IEEE) and CIGRE have cooperated in the research on ±600 kV, ±1000 kV, ±1200 kV DC transmission system, and ABB Co., Ltd. has also explored these directions, so far, it has not targeted at ±800 kV Unified technical reference specification for insulation coordination of HVDC transmission technology[6].

2. Research foundation of overvoltage in HVDC transmission system

2.1. Overview of Internal Overvoltage

The Internal Overvoltage of DC transmission system is mainly caused by switch operation or system fault, which is essentially the oscillation and conversion of electromagnetic energy in the power grid during the transmission process through inductors or capacitors. The internal overvoltage is higher than the rated allowable voltage of power grid, which can be instantaneous or lasting for a long time, which will threaten the safety and stability of electrical devices. The purpose of studying overvoltage in DC system is to directly study the insulation coordination level, which is helpful to the selection of insulation level of lines and converter station equipment in the system. In order to facilitate the following chapters, this paper divides the overvoltage of HVDC transmission system into AC side overvoltage of converter station and DC side overvoltage of converter station.

2.1.1. AC side overvoltage. In this section, the AC side overvoltage of converter station is divided into switching overvoltage and temporary overvoltage.

(1) Switching overvoltage. Switching over-voltage is essentially an electromagnetic transient process. The most typical source of this transient process is the wrong operation or system fault of circuit breakers, grounding switches and other equipment.

(2) Temporary overvoltage. Summarizing many years of practical engineering experience, it can be found that the overvoltage type of AC bus in converter station is usually typical temporary overvoltage, which will directly affect the scheme layout of AC bus and converter arrester.

2.1.2. DC side overvoltage. The two main sources of DC side overvoltage are DC side of converter station and DC line. The typical Overvoltage on DC side of converter station includes temporary overvoltage, switching overvoltage, lightning overvoltage and so on. The typical Overvoltage on DC line mainly includes lightning overvoltage and switching overvoltage. The common causes of overvoltage at DC side are as follows:

(1) In bipolar operation, one pole of DC transmission line is short circuited to ground, which will cause switching overvoltage on the other normal pole.

(2) In DC system, the protection action on the transmission line will lead to emergency stop operation.

(3) The AC and DC filters are switched on line.

(4) The change of operation mode of HVDC transmission system.

Among the above reasons, the first type of overvoltage will threaten the overvoltage protection and insulation of DC switch in converter station, and it involves the re setting and planning of tower heads at both ends of transmission line.
2.2. Analysis of overvoltage mechanism in single pole earth fault

There are a lot of inductive and capacitive components in HVDC transmission system, so there is coupling effect between two poles in the system. When one pole has grounding fault, overvoltage will be generated on the other non-fault pole. In the electrical analysis, the phase mode transformation method can appropriately transform the various electrical quantities on the DC transmission line, such as transforming the voltage and current vectors into the corresponding modulus, so as to minimize the possibility of coupling relationship between the multiple electrical quantities of the multi-phase system, so as to simplify the analysis process, that is, to decouple the multiphase system. Therefore, this paper mainly uses the phase mode transformation method to analyze the overvoltage generation mechanism of single pole grounding short circuit [22]. Figure 1 shows the HVDC system in bipolar operation mode.

![Figure 1: Simplified diagram of DC bipolar transmission](image)

In the process of calculation and derivation, it is assumed that the EMF of the line at the rectifier side and the inverter side is the same, and both of them are specific constant values, i.e. Under ideal conditions, the DC transmission line in question should be lossless and the fault point should be set at the midpoint of the negative line. Using the phase mode transformation method, we can get the following results:

\[
\begin{bmatrix}
U_a \\
U_b
\end{bmatrix} =
\begin{bmatrix}
1 & 1 \\
1 & -1
\end{bmatrix}
\begin{bmatrix}
0 \\
U_1
\end{bmatrix}
\]

(1)

Where \(U_a\) and \(U_b\) represent positive and negative DC voltage respectively; \(U_0\) and \(U_1\) represent zero sequence voltage and positive sequence voltage respectively. The initial boundary conditions are considered:

\[U_a = 0, i_b = 0\]

(2)

Where \(i_b\) is the DC current of the positive electrode. From equations (1) and (2), it can be concluded that:

\[
\begin{cases}
U_a + U_i = 0 \\
i_0 = i_1
\end{cases}
\]

(3)

Where \(i_0\) and \(i_1\) represent zero sequence current and positive sequence current respectively. Equation (3) is the critical condition of the line in case of single pole grounding short circuit. It is not difficult to find out that the zero sequence and positive sequence circuits are in series.

3. Simulation on overvoltage of HVDC transmission

In this chapter, combined with the famous ±800kV Yunnan-Guangdong HVDC transmission project, some data are simplified and some indexes are reduced. The simple mathematical model of ±500kV monopole DC project is built by PSCAD/EMTDC software, and the voltage waveform of each key point after AC side grounding fault is recorded in detail, and the different effects of AC side grounding fault on inverter side of rectifier side are compared and analyzed.

3.1. Brief description of system parameters

In this paper, a simplified ±500kV single pole HVDC transmission model is established by referring to the structure of Yunnan Guangdong project to analyze the principle and phenomenon of overvoltage. Figure 2 is the structure diagram of the monopole DC project built in this paper, and Figure 3 is the
equipment layout of the converter station on the rectifier side. Combined with the two figures, it is not difficult to see that the whole system includes rectifier power supply, inverter power supply, converter transformer, AC / DC filter, DC transmission line and other modules. The top-down Y/Δ and Y/Y series connection modes are selected for converter transformer.

![Figure 2:  ±500kV single pole HVDC transmission model](image1)

![Figure 3: Equipment layout in rectifier side converter station](image2)

3.2. simulation of AC side grounding fault

Due to the limited space, this paper only studies the simulation of single-phase grounding short-circuit fault.

In order to facilitate the analysis and comparison of the results, according to the three-phase symmetry of the circuit, this paper only simulates the single-phase grounding short-circuit of phase a. Most of the AC capacitors of the rest of the system are operating at the low voltage of the whole system.

![Rectifier side AC bus voltage (phase a)](image3)
When filling in the parameters, it is required that the single-phase grounding short-circuit of the AC bus at the rectifier side starts at 0.4 s, and the short-circuit duration is 100 ms. The simulation and comparison of the DC transmission poles at the rectifier side and the inverter side are conducted, and the voltage at both ends of the C1 element of the high-voltage capacitor in the HP3 AC filter in Fig. 3-6 is simulated and tested. The relevant waveform is shown in Figure 4.

Through the above simulation calculation, it can be found that:

1. In the case of single-phase grounding short circuit, the AC bus at the rectifier side will produce large extreme over-voltage. The over-voltage at the outlet of DC transmission line at the rectifier side is about 1.2 p.u. (1 p.u. = 500 kV), and the over-voltage level at the inverter side is 1.17 p.u. Therefore, it can be concluded that the over-voltage level at the DC line outlet at the rectifier side is higher than the corresponding overvoltage at the inverter side. At the same time, single-phase grounding will have a slight impact on the AC filter at the rectifier side, and an overvoltage of 335 kV will be generated at C1 ends of HP3 filter during fault recovery.

2. In the case of single-phase grounding short circuit, there is no over-voltage on the AC bus at the inverter side, and the voltage amplitude at both ends of C1 element in the AC filter is not increased. The outlet voltage of DC transmission line will gradually return to the rated state before stable operation after short-term oscillation, and will not affect or threaten each component of AC filter. Compared with the final voltage waveform, it can be found that the voltage generated by single-phase grounding at the inverter side will have more severe oscillation and fluctuation than that when the rectifier side is single-phase grounded.

4. Simulation analysis

Although this paper only simulates the voltage at both ends of DC transmission line and main capacitor when AC side of converter station occurs specific fault, it can be considered from many aspects in terms of limiting measures. The influencing factors and limiting measures related to overvoltage mainly include the following aspects:

1. DC control system. The overvoltage generated on DC transmission line is not only related to the electromagnetic coupling between the positive and negative poles caused by capacitance, but also
related to the traveling wave propagation speed at the coupling induction. However, the time taken by DC protection device to send out overvoltage or fault protection command is generally much longer than that of traveling wave transportation, so the control characteristics of DC system have little influence on the extreme value of overvoltage. Can not limit the line overvoltage amplitude.

(2) Lightning arrester shall be installed on the tower at the middle point of the line. According to the test of practical operation, it is found that the over-voltage effect can be reduced by installing appropriate arrester on DC transmission line. The most obvious effect of limiting overvoltage is installing arrester at the midpoint of transmission line, and the energy consumption of arrester is very small, which can be ignored.

(3) The main capacity parameters of DC filter are optimized. The difference of DC filter will affect the overvoltage at the middle point of the line and at both ends of the converter station. Changing the parameters of DC filter means changing the impedance characteristics of both ends of the whole system, and the stored energy will directly change the extreme value of overvoltage. The results show that the larger the main capacitance of DC filter is, the maximum overvoltage extremum will be generated. Therefore, properly reducing the main capacity of optimized DC filter is conducive to suppressing the impact of Overvoltage on lines and systems.

5. Conclusion

On the basis of studying and classifying the fault Overvoltages on both sides of converter station, this paper expounds in detail the overvoltage phenomenon when the switching overvoltage of AC network side reaches the DC side and the DC transmission line is short circuited. After selection, PSCAD simulation software is used to build the mathematical model with reference to ±800kV Yunguang UHVDC. This paper mainly studies the situation of single-phase and three-phase grounding short-circuit at rectifier side and inverter side respectively, and analyzes the voltage of each point of DC transmission line in converter station and the voltage at C1 two ends of AC filter sub module, and summarizes the similarities and differences of over-voltage in waveform results. The main research work of this paper is as follows:

(1) Compared with AC system, DC transmission system has more devices, so its operation characteristics are more complex, and the overvoltage level caused by operation discomfort or fault is also very complex. This paper studies the common overvoltage types in DC transmission project.

(2) This paper analyzes the block models of converter, converter, DC transmission line, AC / DC filter and hierarchical structure of DC control in the actual Yunnan Guangzhou UHVDC project, so as to build a simplified and feasible simulation model of HVDC system under unipolar operation mode.

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