Research on the Impact of Xiamen VSC-HVDC on the Short-circuit Current Level of the Power Grid and the Suppression Measures

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Abstract: After Xiamen VSC-HVDC Project is put into operation, it can improve the power supply capacity and reliability of Xiamen Power Grid. But at the same time, it also brings new problems to the operation of the power grid, among which the short-circuit current problem is particularly prominent. In the preliminary analysis of power grid operation, using the short-circuit current program (PSD-SCCP) commonly used in domestic power grid simulation analysis to calculate, it is found that VSC-HVDC can provide a large short-circuit current when the AC grid is short-circuited, causing the short-circuit current levels of multiple 220kV busbars of the Xiamen Power Grid to approach or exceed 50kA, which brings greater pressure on the adjustment and arrangement of the grid operation mode. Therefore, it is necessary to study the true level of the impact of Xiamen VSC-HVDC on the short-circuit current of the AC grid based on the actual control logic of the Xiamen VSC-HVDC project, in order to propose more accurate short-circuit current suppression measures to achieve bipolar operation of Xiamen VSC-HVDC.

1. Introduction

Xiamen VSC-HVDC Technology Demonstration Project is the world's first high-voltage large-capacity true bipolar flexible HVDC project. Since it was put into operation at the end of 2015, it has been playing an important role in ensuring the reliable power supply of loads in Xiamen Island as the fourth channel for Xiamen to enter the island. At the same time, VSC-HVDC is also a new type of transmission technology that has developed rapidly in recent years [1-4]. And with the continuous deepening of operating practices, it also faces many technical problems that need to be further studied and solved. Among them, the level of the short-circuit current contributed by VSC-HVDC when the AC Short-Circuit Fault is one of the key concerns of the current operation of the Fujian power grid.

At present, the existing short-circuit current calculation standards and methods do not involve the influence of VSC-HVDC on the short-circuit current of the AC system during the AC Short-Circuit Fault. The short-circuit current program (PSD-SCCP) commonly used in domestic power grid...
simulation analysis adopts a conservative method when considering the effect of VSC-HVDC on the short-circuit current of the AC system, resulting the short-circuit current levels of multiple 220kV busbars of the Xiamen Power Grid to approach or exceed 50kA, which brings greater pressure on the adjustment and arrangement of the grid operation mode. In order to ensure the safe operation of the power grid, it was forced to make Xiamen VSC-HVDC unipolar operation for a long time in actual operation, which limited the full utilization of flexible DC transmission capacity.

Relevant scholars have given the calculation method of the short-circuit current of the LCC-HVDC to the grid[5]. And some studies have pointed out that the three-phase short-circuit fault of the AC system on the inverter side of the LCC-HVDC will only affect the DC component of the short-circuit current. The research on the short-circuit characteristics of the AC side of VSC-HVDC focuses on the impact of the asymmetric faults on the AC side of the converter station on the control system of the converter station, but there is no clear explanation about whether it provides short-circuit current and the influencing factors and level of short-circuit current. Therefore, most of the existing research methods[7-8] are too optimistic or too conservative when calculating the impact of VSC-HVDC on the short-circuit current in actual engineering, and they have failed to give a more accurate calculation.

In order to more accurately grasp the impact level of Xiamen VSC-HVDC on the short-circuit current of the AC system, this paper establishes an electromagnetic transient simulation model of Xiamen power grid with the actual control and protection logic of Xiamen VSC-HVDC based on PSCAD/EMTDC at first. Then the influence level of Xiamen VSC-HVDC to the short-circuit current of the grid is studied. Finally, it is studied the corresponding suppression measures according to the simulation results.

2. The key influencing factors of VSC-HVDC contribution short-circuit current

According to the research in [9], the key influencing factors of VSC-HVDC contribution short-circuit current include the VSC-HVDC capacity, the limiter setting value, the inner and outer loop limit strategy of VSC-HVDC, electrical distance between short circuit point and converter station, etc. The VSC-HVDC capacity and the limiter setting value mainly affect the output amplitude of VSC-HVDC. The inner and outer loop limit strategy of VSC-HVDC and electrical distance between short circuit point and converter station mainly affect the output phase of VSC-HVDC.

2.1. Influencing characteristics of amplitude

In order to prevent IGBT equipment from being damaged by over-current in case of fault or interference, current limiting measures are usually added to the control link to limit the current output amplitude of converter station. The limiter setting k is usually 1.05-1.1, and the reference value is the rated current of VSC-HVDC. The steady-state output current of VSC-HVDC after fault $I_{dc,max}$ is as follows.

$$I_{dc,max} = k \times \frac{S_{vsc}}{\sqrt{3}U_N}$$

(1)

It can be seen from the above formula that: (1) in the steady-state phase after fault, the output current of VSC-HVDC reaches the limiter limit, and the larger the limiter value k is, the larger the output current of VSC-HVDC is. (2) Under the same limiter value, the larger the VSC-HVDC capacity $S_{vsc}$ is, the larger the output current of VSC-HVDC is.

2.2. Influencing characteristics of phase

2.2.1. The inner and outer loop limit strategy of VSC-HVDC

Common limiting strategies are as follows: equal proportion limiting mode, priority to ensure active power output mode and priority to ensure reactive power output mode. The matching limiting modes of different application scenarios are different, and the proportion of the middle and component of the
output current active id, reactive iq is also different, which will directly affect the phase difference between the VSC-HVDC output current and the AC system. The limiting strategies of VSC-HVDC is shown in Figure 1.

![Fig.1. The limiting strategies of VSC-HVDC](image)

When the d-axis of VSC-HVDC is based on the AC system voltage vector, the higher reactive current component iq is, the greater the phase difference between the VSC-HVDC output current and the AC system voltage is, and thus the smaller the phase difference between the VSC-HVDC output current and the AC system short circuit current. Therefore, the short-circuit current contributed by the priority to ensure reactive power output mode of VSC-HVDC is the largest.

2.2.2 Electrical distance between short circuit point and converter station

The distance between the short circuit point of AC system and the VSC-HVDC directly affects the voltage drop depth of the VSC-HVDC PCC point after the fault, which will trigger different fault crossing protection strategies of the VSC-HVDC. According to the voltage drop depth of the VSC-HVDC PCC point, phase locked protection strategy includes the following two:

2.2.2.1 Phase-locked loop locks after fault

It usually occurs in the symmetrical fault of the VSC-HVDC near zone, and the voltage of the VSC-HVDC PCC point drops to the lock-in threshold of the phase-locked loop. At this time, the phase of VSC-HVDC output current is related to the grid operation mode, so it cannot be determined.

2.2.2.2 Phase-locked loop works normally after fault

At this time, VSC-HVDC operation is in equivalent current source state. The reference phase of the VSC-HVDC output is the voltage phase of the PCC point, and is related to the proportion of active and reactive components of the VSC-HVDC output current.

3. Analysis of the influence of Xiamen VSC-HVDC on the short-circuit current level of power grid

3.1 The electromagnetic transient simulation model of Xiamen power grid with Xiamen VSC-HVDC

The main control and protection strategies adopted by Xiamen VSC-HVDC are as follows:

1) Fault low-voltage limiting strategy. When the voltage of VSC-HVDC PCC point $U_{vpcc} < 0.2\text{p.u.}$, the limiter value is 0.6; When $0.2 < U_{vpcc} < 0.5\text{p.u.}$, the limiter value is 0.8; When $U_{vpcc} > 0.5\text{p.u.}$, the limiter value is 1.1.

2) The inner and outer loop limit strategy of VSC-HVDC. Xiamen VSC-HVDC mainly adopts equal proportion limiting strategy.

3) Phase locked protection strategy. The phase-locked loop blocking voltage threshold of Xiamen VSC-HVDC is 0.1p.u.. The electromagnetic transient simulation model of Xiamen power grid with Xiamen VSC-HVDC is shown in Figure 2.
Fig.2. The electromagnetic transient simulation model of Xiamen power grid

3.2. Simulation Analysis of Electromagnetic Transient Faults Considering the Influence of VSC-HVDC

The simulation duration is 2s; the fault occurrence time is 1s; the fault duration is 0.1s; the constant AC voltage control mode

3.2.1. Constant reactive power control mode

3.2.1.1. Symmetrical three-phase short-circuit fault

Under three operating conditions of VSC-HVDC, namely full stop, unipolar operation (P=400MW and Q=0Mvar, the same below), bipolar operation (P=800MW and Q=0Mvar, the same below), the calculation results of short-circuit current after the three-phase faults of 220kV busbars such as Hubian, Pengcuo and Haicang are shown in Table 1.

| Operating conditions of VSC-HVDC | Three-phase short-circuit current (kA) |
|----------------------------------|-------------------------------------|
|                                  | Hubian | Pengcuo | Haicang |
| Full stop                        | 40.35  | 40.02   | 40.35   |
| Unipolar                         | 40.91  | 40.44   | 40.46   |
| Bipolar                          | 41.29  | 40.81   | 40.55   |
| Contribution under bipolar (kA)  | 0.94   | 0.79    | 0.20    |

It can be seen from the above table that the short-circuit current contributed by VSC-HVDC is the largest when the Hubian near the Xiamen VSC-HVDC receiving end faults.

In addition, the phase-locked loop is locked when the near-field of VSC-HVDC (Hubian, Pengcuo, etc.) faults, causing the phase of the VSC-HVDC output current to be undefined. Therefore, it is recommended that the VSC-HVDC contribution value take its output current amplitude under the near-field faulting, about 2.13kA.

When the remote zone faults, the phase-locked loop works normally. According to section 1.2 and the above control settings of Xiamen VSC-HVDC, Xiamen VSC-HVDC operation in equivalent current source state mainly injecting active current into the system, and it does not contribute much to the fault point Haicang after the vector superposition, only about 0.2kA.

3.2.1.2. Asymmetric single-phase short-circuit fault

Under the above three operating conditions of VSC-HVDC, the calculation results of short-circuit current after the single-phase faults of 220kV busbars such as Hubian, Pengcuo and Haicang are shown in Table 2.
**TABLE 2. SINGLE-PHASE SHORT-CIRCUIT SIMULATION RESULTS UNDER CONSTANT REACTIVE POWER CONTROL**

| Operating conditions of VSC-HVDC | Single-phase short-circuit current (kA) |
|----------------------------------|----------------------------------------|
| Hubian                           | Pengcuo                                | Haicang                                |
| Full stop                        | 42.38                                  | 41.1                                   | 39.83                                 |
| Unipolar                         | 46.07                                  | 44.64                                  | 40.44                                 |
| Bipolar                          | 49.19                                  | 47.71                                  | 40.83                                 |
| Contribution under bipolar (kA)  | 6.81                                   | 6.60                                   | 1.0                                   |

It can be seen from the above table that: with the same three-phase fault, the short-circuit current contributed by VSC-HVDC is the largest when the single-phase fault occurs in the Hubian. Moreover, under the bipolar operation, the short-circuit current of 220kV busbars such as the Hubian and Pengcuo may exceed 95% of the switching capacity (i.e. 47.5kA).

It is found by simulating that when the VSC-HVDC is in the charging and unlocking operation state, the short-circuit current provided by VSC-HVDC is up to 6.37kA under single-phase fault of Hubian, and this value is derived from the zero-sequence current generated by the VSC-HVDC converter grounding method (Ynd). After unlocking, the contribution of short-circuit current increased by 0.41kA. Combined with the analysis of the normal working principle of the phase-locked loop, this value is the positive sequence current contributed by the VSC-HVDC converter itself.

In summary, under the condition of an asymmetric single-phase fault near the VSC-HVDC, the short-circuit current contributed during the VSC-HVDC running mainly comes from the zero-sequence current generated by the converter transformer grounding, and the value reaches about 6.4kA.

### 3.2.2. Constant AC voltage control mode

The AC voltage control setting of VSC-HVDC Vref is 1.0p.u..

#### 3.2.2.1. Symmetrical three-phase short-circuit fault

Under the above three operating conditions of VSC-HVDC, the calculation results of short-circuit current after the three-phase faults of 220kV busbars such as Hubian, Pengcuo, and Haicang are shown in Table 3.

**TABLE 3. THREE-PHASE SHORT-CIRCUIT SIMULATION RESULTS UNDER CONSTANT AC VOLTAGE CONTROL**

| Operating conditions of VSC-HVDC | Three-phase short-circuit current (kA) |
|----------------------------------|----------------------------------------|
| Hubian                           | Pengcuo                                | Haicang                                |
| Full stop                        | 40.35                                  | 40.02                                  | 40.35                                 |
| Unipolar                         | 41.05                                  | 40.77                                  | 40.72                                 |
| Bipolar                          | 41.44                                  | 41.07                                  | 40.83                                 |
| Contribution under bipolar (kA)  | 1.09                                   | 1.05                                   | 0.48                                  |

It can be seen by comparing Table 1 and Table 3 that: under the same VSC-HVDC transmission power, the short-circuit current provided by VSC-HVDC under constant AC voltage control is larger than that of the constant reactive power control, and the three-phase short-circuit currents contributed to the 220kV busbars such as Hubian, Pengcuo, and Haicang are respectively increased by about 0.15kA, 0.26kA and 0.28kA.

The main reason is that the constant AC voltage control requires more reactive power support capacity, resulting in more reactive component current injected into the AC system, which is equivalent to positively increasing the constant reactive power control setting.

#### 3.2.2.2. Asymmetric single-phase short-circuit fault

Under the above three operating conditions of VSC-HVDC, the calculation results of short-circuit current after the single-phase faults of 220kV busbars such as Hubian, Pengcuo, and Haicang are shown in Table 4.

**TABLE 4. SINGLE-PHASE SHORT-CIRCUIT SIMULATION RESULTS UNDER CONSTANT AC VOLTAGE CONTROL**

| Operating conditions | Single-phase short-circuit current (kA) |
|----------------------|----------------------------------------|

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of VSC-HVDC & Hubian & Pengcuo & Haicang \\
Full stop & 42.38 & 41.1 & 39.83 \\
Unipolar & 46.41 & 44.98 & 40.64 \\
Bipolar & 49.55 & 48.11 & 41.08 \\
Contribution under bipolar (kA) & 7.17 & 7.0 & 1.25 \\

It can be seen by comparing Table 2 and Table 4 that: with the same three-phase fault, the short-circuit current provided by VSC-HVDC under constant AC voltage control is larger than that of the constant reactive power control, and the single-phase short-circuit currents contributed to the 220kV busbars such as Hubian, Pengcuo and Haicang are respectively increased by about 0.36kA, 0.4kA and 0.25kA.

4. Research on Short Circuit Current Suppression Measures Provided by VSC-HVDC

It can be seen from the analysis in section 2 that Xiamen VSC-HVDC provides two parts of short-circuit current to the AC system after entering. One is that the short-circuit current of the positive sequence component provided by the VSC-HVDC converter itself, which is up to 2.13kA for VSC-HVDC. The second is the zero-sequence current provided when an asymmetrical short-circuit fault occurs due to the VSC-HVDC commutation connection (Ynd), which is up to 6.4kA for VSC-HVDC.

Therefore, combined with the actual operation of Xiamen power grid, the measures and feasibility of suppressing the short-circuit current provided by VSC-HVDC are studied from two aspects: control strategy of VSC-HVDC and grid structure.

4.1. Control strategy of VSC-HVDC

The purpose of adopting control strategy of VSC-HVDC is to suppress the positive sequence component short-circuit current contributed by the converter, and the following two schemes are proposed:

(1) Dropping low-voltage limiting setting. Set a lower low-voltage limiting multiple during fault crossing, but it will weaken the ability to support active power and reactive voltage during fault crossing.

(2) Dropping constant reactive power control setting. The most effective solution is to change reactive power control setting to a negative value. At this time, the phase difference between the reactive current of VSC-HVDC output and the short-circuit current of AC system is close to 180 degrees, which suppresses the short-circuit current at the fault point. However, this scheme is mainly applicable to the operating conditions with sufficient reactive power in the power grid.

Taking the three-phase short-circuit fault at the Hubian as an example, the short-circuit current contributed by VSC-HVDC under different reactive power control settings during bipolar operation (P=800MW) is analyzed based on PACAD. The simulation calculation results are shown in Table 5.

| TABLE 5. THE SHORT-CIRCUIT CURRENT RESULTS OF HUBIAN UNDER DIFFERENT REACTIVE POWER CONTROL SETTINGS |
|---|---|---|---|
| short-circuit current(kA) | Bipolar operation (P=800MW) |
| Q=0Mvar | Q=100Mvar | Q=-100Mvar |
| Hubian | 41.29 | 41.36 | 41.23 |
| Deviation from Q=0Mvar | 0 | 0.07 | -0.06 |

It can be seen from the above table that: if VSC-HVDC sends reactive power to the system (the control setting is positive), it will help increase the short-circuit current of the power grid; on the contrary, if VSC-HVDC absorbs reactive power from the system (the control setting is negative), it will restrain the short circuit current of the power grid. The feasibility of the above scheme (2) in suppressing short-circuit current is verified.

4.2. Grid structure

The purpose of adopting grid structure is to suppress the zone-sequence component short-circuit current contributed by the commutation, and the following two schemes are proposed:

(1) The neutral points of the four converter transformers are not grounded. At this time, the zero-sequence current contributed by VSC-HVDC under bipolar operation is 0, and the single-phase short-
circuit current of Hubian decreases the most, which can be reduced by 6.4kA. But this scheme should be checked by the design institute in conjunction with other units.

2) Small reactances are added to the neutral points of the four converters. The value of the neutral point small reactance needs to be combined with the development of Xiamen power grid. After accounting, if the neutral point has a small reactance value of 10 ohms, the single-phase short-circuit current of 220kV busbars such as Hubian and Pengcuo under bipolar operation are reduced by about 4kA. But the scheme should also be checked by the design institute in conjunction with other units.

5.Conclusion
This paper carries out simulation analysis of electromagnetic transient faults in Xiamen Power Grid under different control modes and operating conditions based on the actual control logic of Xiamen VSC-HVDC. The short-circuit current levels contributed by Xiamen VSC-HVDC with different fault types and different fault points are given, and its main sources are analyzed. Finally, corresponding suppression measures are proposed, but it needs to be further checked and verified in accordance with the requirements of all aspects of the operation of Xiamen Power Grid. The main conclusions are as follows:

(1) Under the same VSC-HVDC transmission power, because of the need of more reactive power supporting capacity under the constant AC voltage control, so the short-circuit current provided by VSC-HVDC is larger than that of the constant reactive power control.

(2) The Xiamen VSC-HVDC provides two parts of short-circuit current to the AC system after entering: one is that the short-circuit current of the positive sequence component provided by the VSC-HVDC converter itself; the second is that the short-circuit current of the zero-sequence component provided by the VSC-HVDC commutation.

(3) According to the source of short-circuit current contribution of the Xiamen VSC-HVDC, the related measures to suppress the short-circuit current provided by VSC-HVDC are studied from two aspects of control strategy of VSC-HVDC and grid structure.

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