Research on Emergency Control Strategy of Synchronous Condenser for Inhibiting HVDC Commutation Failure

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Abstract. As multi-infeed HVDC systems are integrated into power grid, the operation characteristics of power grid have changed significantly. The problems of the shortage of dynamic reactive power reserve and voltage support need the allocation of dynamic reactive compensation device such as synchronous condenser urgently. This paper researches the influence of installing synchronous condenser on system performance in multi-infeed HVDC power grid. Based on the analysis of the defects of synchronous condenser on HVDC commutation failure under existing conventional control mode, this paper presents the emergency control strategy and system architecture with synchronous condenser. In the end, the effectiveness of the proposed control strategy is verified based on the actual grid simulation.

1. Introduction

With the development of HVDC transmission technology in China, numbers of HVDC lines have been built and put into operation in our country such as JinSu, Xitai, Zhaoyi HVDC and so on. The characteristics of power system have changed dramatically which reflects in three main aspects[1-5]. (1) Due to the replacement of regular generator unit by HVDC line, the dynamic reactive power reserve reduces significantly. Meanwhile the short circuit capacity of the system reduces which deteriorates the voltage regulation characteristics; (2) Under normal operating conditions, the reactive power exchanged between converter station of HVDC and power grid is zero. HVDC line does not provide dynamic reactive power to system so that when faults occur, HVDC line needs to absorb a large amount of reactive power which will weaken the ability of resist reactive power assault; (3) During the process of commutation failure, HVDC lines need to absorb a large number of reactive power from system, hence if multiple HVDC lines occur commutation failure simultaneously, the system will bear huge reactive power impact[6]. In order to enhance the stability of UHV AC-DC system with multi-infeed HVDC, a considerable amount of dynamic reactive power must be equipped to complete active power transmission of HVDC.

The dynamic reactive power compensation devices of power system include synchronous condenser, static var compensator (SVC) and static synchronous compensator (STATCOM) and so on. Compared with SVC and STATCOM which are based on power electronic technology, the new large capacity synchronous condenser with the better reactive power characteristics can provide short circuit capacity to system and has the advantages of inhibiting the commutation failure of HVDC. It is better to improve the stability of power system and voltage support[7-9].

Recently, there are numerous researches on the influence of HVDC faults on stability of power grid as well as coordination control. Using emergency control methods such as DC power modulation, pumped-storage cutting, and accurate load shedding to solve the security and stability problems after HVDC faults have been studied in paper [10-12]. Meanwhile, numbers of scholars have studied the integrated and characteristics of synchronous compensator. Paper [13] researches the application of new synchronous compensator in sending and receiving-end system which reduces the risk of commutation failure. However, researches on emergency control with synchronous compensator and applications are seldom, this paper studies the operation characteristics of synchronous compensator and analyses the necessity of the emergency control with synchronous compensator. Then the strategy and architecture with synchronous compensator is the key research content and the effectiveness and feasibility of the strategy is verified through actual power network simulation.

2. Influence of synchronous condenser on system operation

Compared with traditional synchronous generator, synchronous condenser does not have the prime mover and speed control system while it keeps the good reactive power regulation performance which can provide electrodeless continuous adjustment capacitive and inductive reactive power. Because of the sub transient, transient and steady state characteristics, synchronous condenser can provide much reactive power to support system voltage and reduce the chance of HVDC commutation failure when power system faults occur. Meanwhile, when voltage sags sharply, it becomes forced excitation state to support voltage in order to avoid the voltage collapse[13].

2.1. Influence on system operation

Based on the actual power system simulation, the influence of synchronous condenser on system operation in multi-infeed HVDC power grid has been discussed below.

(1)Influence on short circuit current and multi-infeed effective short circuit ratios (MIESCR)

At present, MIESCR is used to measure the support ability of AC system to DC system[14]. The short circuit current and MIESCR of the chosen HVDC line in this paper before and after installing synchronous condenser is shown in Table 1. As the rotating equipment, synchronous condenser increases the level of short circuit current and MIESCR as well as improves support ability of AC network which can be seen from Table 1.

Table 1. Short circuit current and multi-infeed effective short circuit ratios of the HVDC line under different schemes

scheme	short circuit current /kA	short circuit capacity/MVA	MIESCR
without synchronous condenser	34.27	31161.0	3.39
Three synchronous condensers	37.85	34419.3	3.87

(2)Influence on voltage stability level

Because of the ability of supporting dynamic voltage, synchronous condenser can provide dynamic reactive power when system voltage sags because of the less scale of generation unit. Figure 1 shows the voltage variation of converter station when the HVDC line bipolar blocking fault occurred before and after synchronous condenser. It is clear that the voltage rises apparently.

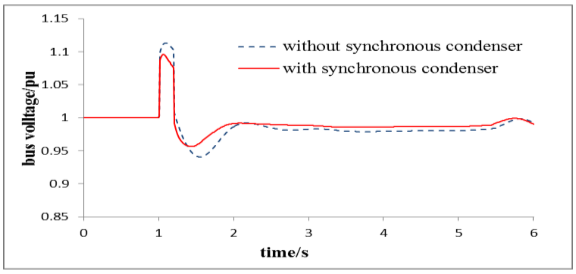

Figure 1. Voltage curve of converter station after HVDC line bipolar blocking

(3)Influence on commutation failure

The numbers of commutation failure can be decreased because of installing synchronous condenser. Table 2 shows the number of three-phase permanent faults in each of 500kVAC transmission line which leads to commutation failure of the HVDC line with and without synchronous condenser. Apparently, the number of faults decreases due to the collation of synchronous condenser.

Table 2. The number of faults leading to commutation failure of HVDC line under different schemes

scheme	the number of faults
without synchronous condenser	86
Three synchronous condensers	78

In these faults, for example, when three-phase permanent fault occurs in a 1000kV AC transmission line, the times of commutation failure of this HVDC line changes from 3 times to 0 time because of the installing synchronous condenser, as shown in Figure 2.

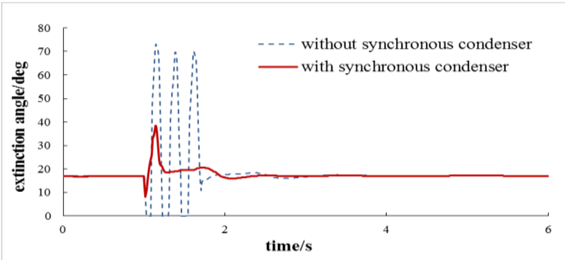

Figure 2. HVDC commutation failure times with and without synchronous condenser

It can be seen that after installing synchronous condenser, the dynamic reactive power reserve is strengthened as well as the commutation failure is inhibited to some extent; however, according to the statistical data in Table 2, the quantity of faults that causes commutation failure of HVDC line is still large, so it is urgent to propose measures to improve the situation of commutation failure.

2.2. Defect of synchronous condenser under conventional control mode

From section 2.1, although synchronous condenser is able to change the situation of commutation failure, it regulates the control mode of reactive power output quickly by following the voltage variation of terminal voltage. While under most circumstances, the voltage after fault cannot maintain on the same level and fluctuates following the fault occurs. In the case, the terminal voltage of synchronous condenser and the voltage of converter station fluctuate simultaneously, hence synchronous condenser cannot generate adequate reactive power instantly and also cannot maintain as forced excitation level. For example, for the same HVDC line discussed above, when three-phase permanent fault of one 500kVAC transmission line which next to the HVDC line occurs, three times commutation failure happens on this HVDC line with three synchronous condensers. The voltage curve of converter station is shown in Figure 3. The voltage sags severely because of converter station next to the fault point. Voltage fluctuates obviously and reactive power output of synchronous condenser fluctuates follow the oscillation as well. In hence, synchronous condenser cannot support to inhibit commutation failure of this HVDC line, as shown in Figure 3.

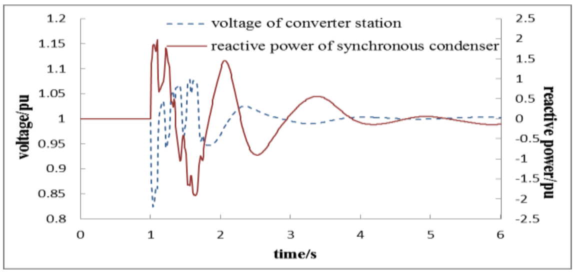

Figure 3. Bus voltage of converter station and reactive power output of synchronous condenser

In the existing Three- defense-line comprehensive defense system, the use of second-defense-line which completes emergency control based on the faults is an effective measure to solve the stability problem of power grid. Therefore, it is useful and urgent to research the emergency control strategy with synchronous condenser. By using fault information to trigger excitation system of synchronous condenser into forced excitation state, synchronous condenser provides emergency reactive voltage support for a certain period of time so that it can improve commutation failure of HVDC system.

3. Emergency control strategy architecture with synchronous condenser

As the commutation failure occurs mostly in the receiving-end network, stability control device can be installed at the converter station of HVDC. Meanwhile, an emergency control main station which used to determine commutation failure of HVDC and operation information of synchronous condenser needs to be built. The main station contacts with other stability control devices of HVDC converter station by communication channel, exchanges information and transfers control commands[15].

The information of the first commutation failure is detected by the control substation of each HVDC converter station and sent to emergency control main station which synthesizes the operation information of synchronous condenser. According to the predetermined emergency control strategy, the main station sends commands to the corresponding synchronous condenser which is forced to maintain reactive power output on a higher level. The control executive station of synchronous condenser is built which is responsible for monitoring and sending operation status of the synchronous condenser and executing the command from the emergency control main station.

The specific emergency control logic is discussed as the following section.

(1)The control substation of each HVDC converter station receives the commutation failure message and sends the information to emergency control main station.

(2)The control executive station of synchronous condenser acquires the operation information of each synchronous condenser and communicates with the emergency control main station directly as well as the state information.

(3)The emergency control main station obtains the bus voltage information of each HVDC inverter station and the operation information of each synchronous condenser in the power grid including commutation failure message of HVDC lines in real time.

(4)After obtaining the commutation failure information, emergency control main station synthesizes the current status of each synchronous condenser and sends the excitation multiple and duration time commands to the corresponding synchronous condenser following the predetermined emergency control measures.

(5)The control executive station of synchronous condenser receives all the command and sends it to the excitation control system which executes emergency control command. After the duration time or triggering over-excitation protection limit, synchronous condenser completes emergency control. The control executive station monitors operation status and sends them to control main station.

Also, it should be pointed out that, when considering the emergency control strategy with synchronous condenser, the synchronous condenser in the near region of HVDC line should be priority considered. When serious faults occur in the near area of HVDC line, it is still necessary to adopt HVDC bipolar blocking, generator tripping and load shedding measures to ensure the security and stability of power grid.

4. Case study

Taking the actual power grid simulation as an example, when three-phase permanent fault of one 500kVAC transmission line occurs as described in section 2.2, three times commutation failure happens on this HVDC line under the traditional control mode of synchronous condenser. The active power of HVDC line and reactive power output of the synchronous condenser is shown in Figure 4, reactive power output of synchronous condenser cannot maintain on the forced excitation level which is ineffective to support HVDC line commutation failure.

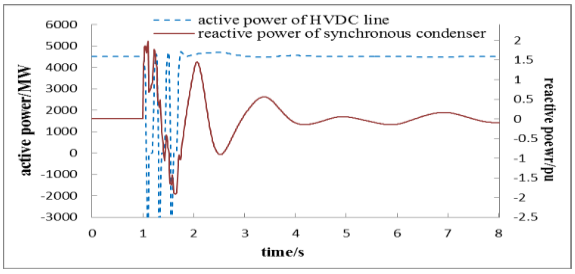

Figure 4. Power curve under the normal control of synchronous condenser

Then the optimization control strategy mentioned in this paper is used and under the same fault the times of commutation failure of the same HVDC line reduces from 3 times to twice. In this case, the synchronous condenser is forced to 2.5 times of excitation current once receiving the first commutation failure information. The active power of HVDC line and reactive power output of the synchronous condenser considering the optimization strategy with synchronous condenser is shown in Figure 5. As shown, synchronous condenser maintains on the forced excitation level for a duration period of time which inhibits commutation failure effectively.

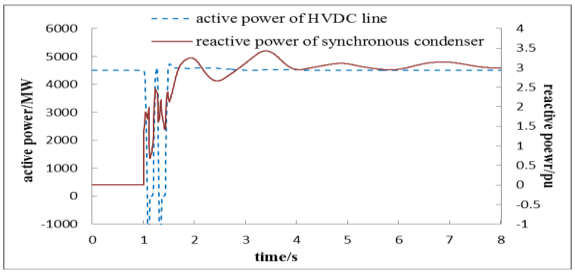

Figure 5. Power curve under emergency control with synchronous condenser

5. Conclusion

Commutation failure of Multi-infeed HVDC has become an important factor affecting the security and stability of power grid currently. In order to improve the dynamic reactive power reserve and prevent or reduce the situation of commutation failure, the dynamic reactive power compensation devices especially synchronous condenser have been used widely. At present, a large number of simulation analysis shows that although the allocation of synchronous condenser has decreased the probability of commutation failure to some extent, it cannot exert the capabilities of dynamic reactive power support completely only depending on its own response. Therefore, based on the study of the influence of synchronous condenser on the operation characteristics of power grid, this paper proposes the strategy and system architecture of emergency control optimization strategy with synchronous condenser. The commutation failure information of HVDC lines is used to trigger the synchronous condenser to emergency control so that synchronous condenser can be maintained on the forced excitation level which will inhibit continuous commutation failure of HVDC lines and ensure the security and stability operation of power grid.

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