Analysis of influence of energy storage system parameters on HVDC commutation failure overvoltage

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Abstract. Overvoltage is a common fault in high voltage direct current (HVDC) transmission systems, which directly affects the safe and stable operation of the system. Energy storage system has been widely used in power system because of its fast response speed, high precision and bidirectional energy transmission. As a variable parameter, the low voltage traverse active power coefficient directly affects the overvoltage of commutation failure in HVDC system. In this paper, the influence of transient characteristics and energy storage parameters on commutation failure overvoltage of energy storage system connected to HVDC is analyzed. Based on PSASP simulation, combined with the actual characteristic setting parameters of a power grid in northwest China, the positive correlation between energy storage low-pass active power and transient overvoltage of HVDC system commutating failure is verified by dynamic trajectory sensitivity analysis, and the optimization space of HVDC energy storage system is expanded.

1 Introduction

In order to promote the goal of “carbon neutral carbon peak”, it is of great significance to apply clean energy in power production. In China, energy production and consumption vary widely by region, so large-scale transmission of energy is required. High Voltage Direct Current (HVDC) has many advantages such as large transmission capacity and low transmission loss, and is widely used in power transmission systems [1].

In the study of commutation failure mechanism, most of the current focus on the receiving end AC failure, but because of the electrical coupling between the sending end and the receiving end, the failure of the sending end AC system will also cause the inverter commutation failure. In the AC fault of the sending end, the commutation failure will be caused by excessive current under minor faults and improper interaction of the controller under serious faults, and the bad activation of the current deviation link during the recovery process will also cause the commutation failure. In the process of controlling the response, excessive reactive power consumption of the inverter is the main reason for the commutation failure.

Commutation failure is one of the common faults in HVDC system, which can cause transient overvoltage and voltage fluctuation in the transmission network. When the total DC capacity of the power grid is too large, the overall strength of the power grid is weak compared with the DC capacity of the power grid, resulting in a more obvious impact of DC faults on the power grid. With the continuous investment of energy storage systems in power grids, the parameters of energy storage systems have more and more influences on the failed overvoltage of HVDC systems [2].

At present, a large number of studies have been done at home and abroad on the problems related to the commutation failure of HVDC system and energy storage [3–7]. Among them, literature [3] has analyzed the correlation between the transient overvoltage level and the short-circuit ratio of converter station, the short-circuit capacity of converter station, and the voltage control capability of near-area system and the safety control. Literature [4] proposes a new technology combining energy storage technology and reactive power compensation technology to avoid DC commutation failure. Literature [5] has a guiding significance for HVDC to quantitatively evaluate the transient performance indicators of AC and DC power systems and to determine the planning, design and scheduling operation of AC and DC power systems. Literature [6] proposes a coordinated control strategy for energy storage active power output to suppress the subsequent problems of commutation failure.

Literature [7] studies that the energy storage system improves the steady-state transmission power of the UHV transmission channel and, as a cross-region standby source, reduces the start-up of the thermal power unit at the sending end to increase the new energy generation space. The above literature analyzed the transient overvoltage problem of high-voltage transmission system and the DC commutation failure based on energy storage technology, but did not study the influence of energy storage system parameters on the commutation failure overvoltage.

This paper analyzes the influence of low voltage through active power coefficient of energy storage
system on transient overvoltage of HVDC system after commutation failure, and simulates it with PSASP under fault through control strategy based on a DC power grid model in China.

2 The basic principle of transient overvoltage in HVDC commutation failure and the blocking fault crossing strategy

2.1 Generation mechanism of transient overvoltage in HVDC system

HVDC system is an "AC-DC-AC" mode of operation, which enhances line reliability, improves transmission efficiency, and saves economic costs. Its structure is shown in Figure 1.

![Figure 1 HVDC transmission system](image)

When the commutation fails, the DC voltage at the receiving end decreases due to the direct conduction of the receiving end inverter, and the DC current increases rapidly, resulting in an increase in reactive power consumed by the system. Because reactive power stability is almost constant and there is a certain time delay between the rectifier station and the rectifier station, the reactive power consumed by the rectifier station is greatly reduced. At this time, the excess output reactive power flows to the DC system, resulting in transient overvoltage at the transmission end of the grid.

2.2 The blocking fault crossing strategy

Most HVDC systems use modular multilevel converters (MMC) as their topologies. When the receiving end system is faulty, the fault current will lead to continuous commutation failure, resulting in transient overvoltage of the bus voltage at the DC end for several times, which threatens the safe operation of the system. Therefore, it is necessary to block the fault by blocking the fault through strategy.

Fault processing is divided into two stages: before the fault and through the fault. The equivalent circuit before the fault is shown in Figure 2.

![Figure 2 Equivalent circuit before fault](image)

The equation of free discharge can be obtained as shown in the figure.

$$\frac{d^2 i_{k}}{dt^2} + R \frac{di_{k}}{dt} + \frac{1}{L C} i_{k} = 0 \quad (1)$$

At the moment of DC blocking, the equivalent diagram of the switching tube circuit in the topology module is shown in Figure 3.

![Figure 3 Blocking instantaneous fault equivalent circuit](image)

The loop equations of the bridge arm and the lower bridge arm can be listed:

$$u_k - L_s \frac{di_k}{dt} = L \frac{di_{ko}}{dt} + R i_{ko} + u_{ko} + u_{ps} \quad (2)$$

$$u_k - L_s \frac{di_k}{dt} = -L \frac{di_{ko}}{dt} - R i_{ko} - u_{ko} + u_{no} \quad (3)$$

The current relationship between the bridge arm and the capacitor voltage is as follows:

$$i_k = i_{ko} - i_{en} \quad (4)$$

$$\sum i_{ko} = \sum i_{en} = i_{ke} \quad (5)$$

The relationship between the current of the bridge arm and the capacitor voltage is as follows:

$$4C \sum \frac{du_{ko}}{dt} = \frac{4C}{N} \sum \frac{du_{en}}{dt} = i_{ke} \quad (6)$$

According to formula (2) ~ (6),

$$\frac{d^2 i_{en}}{dt^2} + R \frac{di_{en}}{dt} + \frac{1}{L C} i_{en} = 0 \quad (7)$$
By comparing formula (2) and formula (7), the direction of capacitor voltage and bridge arm current is different. Due to the counter-electromotive force action of the module capacitor, the current drops to a value approaching 0 in a few milliseconds, at which time there are two paths as shown in Figure 4.

![Figure 4 Circuit in the locked state](image)

In order to ensure the complete blocking of the converter, conditions must be met: the back electromotive force provided by the module capacitor is greater than the line voltage amplitude[10]. The specific expression is:

\[
\begin{aligned}
&\frac{3}{2}N U_c > \sqrt{3}U_n \\
&N U_c > \sqrt{3}U_n
\end{aligned}
\]  

(8)

The fault is cleared by realizing the blocking of the converter, so that the HVDC system can return to normal steady state operation.

3 Analysis of influence of energy storage system parameters on commutation failure overvoltage

Transient overvoltage is a process of low voltage and high voltage. When the system sending terminal voltage exceeds the national standard threshold, the system enters voltage crossing. The energy storage system can enhance the low voltage crossing ability of the system by absorbing the overvoltage of the bus at the sending end. The reactive power emitted by the energy storage system to the HVDC system during the low voltage crossing supports the grid voltage to recover to the ideal range. When the reactive power emitted by the energy storage system is insufficient, the converter controls and adjusts the reactive power output according to the voltage drop degree of the grid, supports the voltage recovery, and then improves the low voltage crossing capability of the system.

Limited by the rated power of the converter, the maximum reference value of the active current is:

\[
i_{\text{idref}} = \sqrt{\frac{i_{\text{gmax}}^2 - i_{\text{qref}}^2}{i_{\text{gmax}}}}
\]

(9)

Where, \(i_{\text{gmax}}\) is the maximum allowable current of the converter, and \(i_{\text{qref}}\) is the reference value of reactive current. The DC side voltage is adjusted by the value of idref, so as to improve the low voltage crossing ability of the system.

Active current control instruction for low voltage crossing process:

\[
I_{p,LVRT} = K_{1,p,LV}u_g + K_{2,p,LV}I_{p0} + I_{set,LV}
\]

(10)

Reactive current control instruction for low voltage crossing process:

\[
I_{q,LVRT} = K_{1,q,LV}(0.9 - u_g) + K_{2,q,LV}I_{q0}
\]

(11)

Suitable energy storage parameters are used to realize the impact on the low voltage crossing ability. Table 1 shows the value range of energy storage parameters.

**Table 1** Range of energy storage parameters

<table>
<thead>
<tr>
<th>Parameter content</th>
<th>Parameter name</th>
<th>Parameter analysis range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low penetration active power coefficient</td>
<td>(K_{1,p,LV}, K_{2,p,LV})</td>
<td>0.1-1</td>
</tr>
</tbody>
</table>

4 Analysis of the influence of stored low pass active power on overvoltage after DC commutation failure

Now we combine the actual characteristics of a power grid in northwest China for simulation analysis. Simulation boundary: The fault is set to the most serious fault, HVDC 4 commutation failure and blocking fault to test the sensitivity of energy storage parameters to the machine terminal voltage peak. The DC power transmission is 6 million kilowatts, and the photovoltaic parameters are set as the recommended parameters for the optimization of the DC power transmission system. The installed energy storage capacity is 1.285 million kW.

Where: 4 commutation failure DC blocking fault set to: Dc 1s starts the first commutation failure power fluctuation process, 1.2s starts the second commutation failure power fluctuation process, 1.4s starts the third commutation failure power fluctuation process, 1.6s starts the fourth commutation failure power fluctuation process, 1.7s starts the DC blocking, 1.8s cutting filter, and the second commutation failure power fluctuation process. The power fluctuation process of each commutation failure starts from DC power to recover to more than 90% of rated power with a duration of about 0.2s.

The variable parameter changed in the parameters of the energy storage model in PSASP is the energy storage low pass active power. Other parameters are set as follows:

- Low penetration reactive power support coefficient 2, high penetration reactive power support coefficient 1.5, active power recovery rate 3 p.u/s. The low-penetration active power support coefficients were set to 0.2, 0.5 and 1 respectively.

The system voltage change curve is shown in the figure 5.
Figure 5 system voltage change curve

A bus initial voltage 1.00063 pu; B bus initial voltage 0.99993 pu; C The initial voltage of the energy storage terminal is 0.99086pu. As shown in Table 2, it is the highest point voltage under different active power coefficients.

Table 2 The highest point voltage of the system under different active power coefficients

<table>
<thead>
<tr>
<th>PEAK</th>
<th>Coefficient of active power</th>
<th>0.2</th>
<th>0.5</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A busbar peak</td>
<td></td>
<td>1.20119pu</td>
<td>1.20159pu</td>
<td>1.20224pu</td>
</tr>
<tr>
<td>B busbar peak</td>
<td></td>
<td>1.22061pu</td>
<td>1.22102pu</td>
<td>1.22176pu</td>
</tr>
<tr>
<td>C Energy storage terminal peak</td>
<td></td>
<td>1.18999pu</td>
<td>1.19025pu</td>
<td>1.19066pu</td>
</tr>
</tbody>
</table>

According to the simulation results, during fault recovery, due to energy storage receiving power, the smaller the coefficient, the greater the change of energy storage receiving power, the heavier the power flow, and the decrease of transient overvoltage.

5 Conclusions

Transient overvoltage is caused by commutation failure in HVDC transmission system. In this paper, the influence of stored low pass active power on the voltage drop of commutation failure and the transient overvoltage of blocking under the fault pass control strategy is studied. The following conclusions are obtained:

The smaller the active power coefficient is, the more the energy storage receives, the less the power flow, and
the higher the machine end and system voltage during the low penetration period.

In this paper, there are still many problems worth thinking about in the research on the influence of energy storage system parameters on HVDC commutation failure overvoltage. At present, due to the complex setting of many system parameter nodes, interference parameters are not explored. In the next step, interference factors will be added to the experiment to conduct limitation analysis of the system. It is also necessary to further study the impact of changes in other energy storage system parameters in AC-DC hybrid systems, and how to set parameters to maximize grid efficiency.

References


