Research on Emergency Power Support Method after Distributed Energy Storage System Blocking UHV DC

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Abstract. In order to explore the emergency support effect of distributed energy storage on reducing the peak power flow of AC transmission lines and improving the operating power of DC transmission lines after UHV DC locking fault, based on the analysis of UHV DC locking fault, the active power is provided according to the distributed energy storage system. A mathematical model is established to reduce the peak power flow of AC transmission lines by distributed energy storage after DC locking. According to the relationship between power gap and frequency variation, a mathematical model of distributed energy storage to improve UHV DC operating power is established. Based on frequency variation and inertial response time, a mathematical model of dynamic response time of energy storage output on system support effect was established. Taking Henan Power Grid of UHV AC/DC hybrid operation as an example, the simulation analysis of distributed energy storage system response in two ways is carried out, which verifies the effectiveness of distributed energy storage system for emergency power support method after UHV DC locking.

1. Introduction

The establishment of UHV AC and DC power grids has alleviated the problem of unbalanced distribution of my country's energy centers and load centers [1]-[3]. However, when UHV DC has a blocking fault, it will affect the safety and stability of the hybrid system. Although traditional adjustment methods can ensure the stability of the system, the ability to increase the transmission power of the channel is limited [4]-[6]. Because the distributed energy storage system can provide emergency power support at the level of 100 milliseconds to balance the high power shortage caused by DC blocking, it has become an effective method to adjust the UHV DC blocking failure. With the continuous development of UHV projects, the study of emergency power support methods for distributed energy storage systems is of great significance [7].

Research on emergency measures for failures of UHV AC/DC hybrid systems has achieved certain results. In [8] Ding et al. propose a method to deal with the large-scale DC blocking of the wind and thermal power transmission end system by coordinating the distribution of the removal of the capacitors of the rectifier station and the amount of wind and thermal power. In [9] Li et al. combine the typical power flow of the Northeast power grid to study the high-frequency problems caused by UHV DC blocking, and proposes three lines of defense and comprehensive control strategies as well as effective measures to improve the frequency stability of the power grid. In [10] Guo et al. propose the use of DC power emergency control measures and load shedding measures to replace the stability control strategy of the Xiangnei section to deal with the Jiuquan-Hunan UHV DC bipolar lockout fault. In reference to the problem of UHV DC commutation failure, blocking and other faults affecting the transient stability...
of the hybrid system, In [11] Shu et al. propose an offline simulation analysis method and analyze the power, frequency, and voltage transfer of the system after DC blocking. Furthermore, load shedding strategies are proposed for the disassembly of the tie line. These methods are all traditional adjustment methods. At present, there are few researches on new emergency power support after DC blocking.

Research on the improvement of DC operating power after UHV DC blocking is still blank. Therefore, based on the analysis of UHV DC blocking faults, this paper establishes a distributed energy storage system to reduce the peak power flow of AC transmission lines, increase DC operating power and energy storage. The mathematical model of output dynamic response aging on the system support effect, and two distributed energy storage system response methods are proposed, which provide a new emergency power for the reduction of the peak power flow of the AC transmission line after the UHV DC lockout and the increase of the DC operating power Support method.

2. Analysis of UHV DC Blocking Failure

The input of UHV AC/DC hybrid system has replaced some conventional units in the receiving end power grid. Although it can alleviate the insufficient power supply at the receiving end, it reduces the moment of inertia and frequency modulation characteristics of the receiving end power grid system, resulting in a reduction in the anti-interference ability of the receiving end power grid. When the inverter fails to commutate multiple times, it may cause a DC blocking fault in the UHV DC line.

The occurrence of DC blocking failure has a serious impact on both the sending end and the receiving end system. For the sending-end system, DC blocking breaks the original power balance of the system, the energy of the sending-end system is accelerated, and the rectifier station no longer consumes reactive power, causing a large power surplus in the system and causing a voltage surge. For the receiving-end power grid, DC blocking causes a large loss of receiving-end power, resulting in unstable frequency of the receiving-end system. At the same time, DC blocking causes power flow transfer, and the power flow of AC transmission lines may exceed its static stability limit, causing power and voltage oscillations. If reasonable measures are not taken in time to provide emergency power support after lockout, the scope of the accident will be further expanded and even cause the power grid to collapse.

In view of the DC blocking failure, the measures currently adopted in the operation of the power grid are pre-control measures and stability control measures for the operation mode. Although these measures can ensure the stability of the system, the ability to increase the transmission power of the channel is limited. Distributed energy storage system has been equipped to enter the field of power production and participate in the power system operation control can be used as an effective supplement or alternative to the existing power system load shedding, DC power modulation and other stability control measures. Therefore, research on the use of distributed energy storage emergency power support as a stability control measure to deal with UHV DC blocking failures will promote the application of UHV AC/DC hybrid systems.

3. Distributed energy storage participates in emergency power support analysis

3.1. Distributed energy storage reduces the peak power flow of AC transmission lines

After the DC is blocked, the power flow will shift to the AC transmission line, and the peak of the power flow of the AC transmission line may exceed its static stability limit, causing the power of the AC transmission line to oscillate, and the line is out of step. After DC blocking, the power change of AC transmission line is shown in formula 1:

$$\Delta P_m(t) = Ae^{\sigma t} \sin(\omega t + \varphi)$$  \hspace{1cm} (1)

where $A$ is the oscillation amplitude; $\sigma$ is the attenuation coefficient; $\omega$ is the oscillation frequency; $\varphi$ is the initial phase angle.

After the distributed energy storage system is put into operation, the power change of the AC transmission line is shown in equation 2:
\[
\Delta P_{ac}(t) = Ae^{ot} \sin(ot + \varphi) - \sum_{j=1}^{n} P_{battery,ac,j}
\]  

where \(P_{battery,ac,i}\) is the active power provided by the energy storage system \(i\) to reduce the peak power flow of the AC transmission line; \(n\) is the number of energy storage systems.

It can be seen from equation 2 that the distributed energy storage system provides active power support for the AC transmission line, reduces the power variation of the AC transmission line, reduces the peak power flow of the AC transmission line, and ensures the stability of the system.

### 3.2. Distributed energy storage improves UHV DC operating power

DC blocking will cause the imbalance of active power, and the UHV AC/DC system will take stability control measures. During this period, the power grid at the receiving end is in short supply and the low-voltage state continues. Load load reduction is used to reduce the load pressure at the receiving end and increase the voltage at the receiving end. At the same time, the shortage of power generation leads to a reduction in the frequency of the receiving end grid, and the rotor of the generator set accelerates to provide moment of inertia power. The power shortage and frequency change of the system are shown in equation 3. It can be seen from equation 3 that the frequency deviation of the system at a certain moment is linearly related to the power shortage, and the system frequency difference can be changed by changing the system power shortage.

\[
\begin{align*}
\Delta P_t &= \Delta P_{loss} - \sum_{j=1}^{c} P_{Mj} - \sum_{j=1}^{m} P_{Lj} \\
\Delta f_t &= \frac{\Delta P_t}{f} = \frac{\Delta P_t}{P}(\rho K_g + K_f)
\end{align*}
\]  

where \(\Delta P_t\) is the power shortage of the system at time \(t\); \(\Delta P_{loss}\) is the active power loss of the system due to DC blocking when the distributed energy storage system is not put into use; \(P_{Mj}\) is the moment of inertia power of the \(j\)th generating set when the distributed energy storage system is not put into use; \(c\) is the power generation The number of units connected to the grid; \(P_{Lj}\) is the load-shedding power of the \(j\)-th unit after DC blocking; \(m\) is the number of load-shedding units; \(\Delta f_t / f\) is the frequency deviation of the system at time \(t\); \(P\) is the total active power of the system; \(\rho\) is the grid spinning reserve coefficient; \(K_g\) is the frequency static characteristic coefficient of the generator set; \(K_f\) is the static characteristic coefficient of the load frequency.

If the distributed energy storage system is put into operation, after the stability control measures are implemented, the emergency power support command is issued to the energy storage unit, and the distributed energy storage system is adjusted. The power shortage and frequency change of the receiving end grid after the distributed energy storage system is put into use are shown in equation 4. From equation 4, it can be seen that after the distributed energy storage system is put into use, the power shortage of the receiving end grid is reduced, the frequency deviation is reduced, and the frequency stability is improved.

\[
\begin{align*}
\Delta P_t &= \Delta P_{loss} - \sum_{j=1}^{c} P_{Mj} - \sum_{j=1}^{m} P_{Lj} - \sum_{j=1}^{n} P_{battery,dc,j} \\
\Delta f_t &= \frac{\Delta P_t}{f} = \frac{\Delta P_t}{P + \sum_{j=1}^{n} P_{battery,j}} \times (\rho K_g + K_f)
\end{align*}
\]
where \( P_{M,j} \) is the moment of inertia power of the \( j \)-th generator set after the distributed energy storage system is put into operation; \( P_{\text{battery,dc},i} \) is the active power provided by the energy storage system \( i \) to increase the operating power of UHV DC after DC blocking; \( P_{\text{battery},i} \) is the storage Can reserve power for system \( i \).

In the UHV AC/DC hybrid operation system, the dynamic characteristics of the DC transmission line's voltage and power are mainly determined by the strength of the connected AC system. The investment in the distributed energy storage system improves the frequency stability of the receiving-end power grid and enhances the strength of the AC power grid, thereby increasing the operating power of the UHV DC line.

### 3.3. Dynamic response time of distributed energy storage output on system support effect

The distributed energy storage system provides emergency power support, which not only ensures the stability of the UHV AC/DC system after DC blocking, but also improves the operating power of the DC transmission line. However, the dynamic response time of the distributed energy storage system affects the UHV AC. The supporting effect of the operating power of the DC system and DC transmission lines. When the distributed energy storage system is not put into use, the frequency dynamic characteristics of the UHV AC/DC system are shown in equation 5:

\[
\Delta f(t) = \frac{\Delta P}{K_L} \left( 1 - e^{\frac{-t}{T_j}} \right)
\]

where \( \Delta f \) is the frequency change per unit value based on the rated frequency; \( \Delta P \) is the power disconnection capacity; \( K_L \) is the load regulation effect coefficient; \( T_j \) is the system inertia time constant.

After putting into the distributed energy storage system, the frequency dynamic characteristics of the UHV AC/DC system are shown in equation 6:

\[
\Delta f(t) = \frac{\Delta P}{K_L} \left( 1 - e^{\frac{-t}{T_j + \Delta T}} \right)
\]

where \( \Delta T \) is the increase in system inertia time after the distributed energy storage system is put into operation.

After DC blocking, the inertial response of the generator set is missing, and the distributed energy storage system support makes up for the lack of inertial response and suppresses the system frequency change. Under certain conditions, the faster the dynamic response of distributed energy storage, the greater the inertial response compensated by energy storage. It can be seen from equation 6 that when the time constant of the influence of inertia on the frequency change is larger, the frequency change of the system is smaller, and the support effect on the system is more obvious.

### 4. Simulation of Multi-point Layout Distributed Energy Storage System Connected to Provincial Power Grid

In this paper, an example of Henan Power Grid is built in the PSASP simulation platform. Through the power simulation results of the Changnan Line, the effects of two failure response measures are compared with the use of distributed energy storage systems and load shedding. At the same time, a comparative analysis of the reduction of the peak power flow of the AC transmission line and the increase of the Tianzhong DC operating power after the distributed energy storage system is operated in two response modes.

As of the end of December 2017, Henan had a total of 11000 kV substation with a substation capacity of 6000 MW, 1 UHV DC converter station, and 1 back-to-back converter station. There are 40500 kV substations, with a total substation capacity of 66050 MW and 130 transmission lines. There are 320220
kV substations, with a substation capacity of 102880 MW and 863 transmission lines. The province's total social power consumption has completed 289.31 billion kWh. The UHV AC/DC system runs smoothly during heavy load, the Tianzhong DC power is 5 million kW, and the UHV Changnan Line, Nanjing Line and Nanyang UHV main transformers operate at low power and light load. The transmission capacity of the 500 kV main network section still has a certain margin. Only the Yuzhong-Yunnan East Passage and the Masong section have a utilization rate of 85%.

Distributed energy storage systems are deployed in different areas of the Henan Provincial Power Grid. Among them, the Southern Henan Power Grid, which has a large power gap, is distributed in 10 regions, the Central Henan Power Grid is distributed in 5 regions, and the Henan Province is distributed in 5 regions. The energy storage system in each region is equivalently connected to the 220 kV bus of the power grid, with a maximum capacity of 300000 kW.

The two ways of emergency power support of distributed energy storage system to respond to serious faults are:

Method 1: Under ideal conditions, the stability control and communication response time is 150 ms, and the energy storage device power response time is 100 ms.

Method 2: Under strict conditions, the stability control and communication response time is 250 ms, and the energy storage device power response time is 200 ms.

Consider Henan’s Pingfeng network to supply a load of 47 million kW, Changnan line to send 1 million kW to the south, and Tianzhong DC to 5.4 million kW. Figure 2 shows the simulation results of system operation under three modes of Tianzhong DC bipolar blocking, no stability control measures, 1 million kW load shedding power in Henan, and 1 million kW emergency support of Yuzhong energy storage. It can be seen from Figure 2 that the peak power of the Changnan Line is 5.24 million kW without bipolar lockout measures; when the load shedding power is 1 million kW, the peak power of the Changnan Line is 4.55 million kW; the distributed energy storage system supports 1 million kW, the peak power of Changnan Line is 4.51 million kW. After Tianzhong DC is blocked, the grid load shedding and the emergency support of the distributed energy storage system can effectively reduce the peak power flow of the Changnan Line, and the load shedding power of the same capacity and the power support of the distributed energy storage system have similar effects.

Figure 1 is the power change curve of the Changnan Line under the action of the emergency power support method of the distributed energy storage system, and Figure 2 is the power change curve of the Changnan Line under the action of the emergency power support method without the emergency power support method, through Figure 1 and Figure 2 The comparison shows that the power of the Changnan Line can reach a stable state within 0.2 seconds under the action of the emergency power support method of the distributed energy storage system. If the emergency power support method is not used, the power of the Changnan Line is unstable and exhibits a regular jitter state.
5. Conclusion

Aiming at the problems of high peak power of AC transmission lines and unstable system caused by UHV DC blocking, a distributed energy storage system is proposed to provide emergency power support. The main conclusions are as follows. After DC blocking, the distributed energy storage system can quickly and urgently support power, which can suppress the peak power of AC transmission lines, increase the operating power of DC transmission lines, and ensure the stability of the grid. The effect is similar to that of load shedding and stabilization measures, and the two are interchangeable. The emergency power support of the distributed energy storage system can effectively solve the grid problems caused by the UHV DC blocking failure, and help to ensure the safety of the grid. After the distributed energy storage system urgently supports DC blocking, further research is needed for the delivery and consumption of new energy.

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