Critical Section Channel Maintenance Evaluation Method for Double HVDC Feed-in Grid

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Abstract. In order to ensure stable operation of DC, the dual DC feed grid structure needs to ensure a certain grid strength, but it is necessary to study how to evaluate the impact of critical section maintenance on the AC system. Firstly, the strength evaluation index of the receiving power grid is analyzed. Secondly, an index that characterizes the effects of two DC couplings is proposed. Finally, a critical section channel maintenance evaluation method for double ultra-high voltage DC feed grid is proposed. The effectiveness of the proposed method is verified by the HN Power Grid simulation.

1. Introduction

China's resource endowments are inversely distributed with the load center. The structural imbalance of energy production and consumption, large-scale long-distance transmission has become an inevitable choice [1-2]. With the rapid development of China's HVDC projects, the operation characteristics of the power grid become increasingly complex, due to the influence of the receiving power grid's multi-DC centralized feed pattern and the interaction coupling between AC and DC and different DCs [3-4].

For the multi- HVDC feeding into the power grid, when the electrical distance between different dc converter buses is relatively close, the interaction coupling between the two DC is greatly affected. After the fault occurs in the receiving AC system, the two DCs may turn out simultaneous commutation failure, causing power disturbance to the DC sending end. If two DCs are belong to the same sending end and the same receiving end, when the simultaneous commutation fails, the two DCs generate power disturbance to the same AC sending end, which may cause the power and frequency of the sending end grid to be unstable.

In order to support the stable operation of dual DC, the receiving AC grid needs to maintain a certain grid strength. However, due to planned maintenance and unplanned maintenance, the strength of the AC grid on the receiving end will decrease, and the short circuit ratio(SCR) of the DC converter bus may be reduced due to planned and unplanned maintenance of the line close to the DC converter bus. As a result, the DC cannot be operated at full power and the DC transmission power needs to be decreased to increase the DC converter bus short circuit ratio to an acceptable level. On the other hand, some lines maintenance can reduce the electrical distance between the two DCs, which can reduce the fault area where two DC simultaneous commutation failures are caused by specific fortification failures. For the
dual DC feed into the power grid, it is urgent to carry out channel maintenance evaluation on the basis of considering reducing the area of simultaneous commutation failure.

2. Evaluation index of AC frame strength at receiver

The commonly used receiving power grid strength evaluation indexes are short circuit ration and multi-feed short circuit ratio (MSCR). When simultaneous commutation failure occurs, multi-infeed interaction factor (MIIF) can be considered. In particular, for hierarchical infeed DC, the corresponding strength evaluation index of the receiving end power grid is Hierarchical Infeed DC Short Circuit Ratio (HSCR).

For a single DC, the short circuit ratio (SCR) \[5\] is the simplest and most effective index for determining the strength of the AC system grid.

\[SCR_i = \frac{S_{aci}}{P_{di}} = \frac{U_i^2}{Z_{aci}} \]

In equation (1), \(S_{aci}\) is the AC three-phase short-circuit capacity of the inverter bus of DC \(i\); \(P_{di}\) is the transmission capacity of DC \(i\); \(U_i\) is the voltage of the commutated bus \(i\); \(Z_{aci}\) is the Thevenin equivalent impedance of the AC system.

SCR-based AC grid strength judgment:
- If the SCR is greater than 5, the AC system is strong;
- If the SCR is between 3 and 5, the AC system is strong;
- If the SCR is less than 3, AC system is extremely weak.

For multi-infeed DC grids, the Multi-infeed Short Circuit Ratio (MSCR) \[6\] takes into account the effects of other DCs.

\[MSCR_i = \frac{S_{aci}}{\sum_k P_{dk} \cdot MIIF_{ik}} \]

In equation (2), \(S_{aci}\) is the AC three-phase short-circuit capacity of the inverter bus of the DC \(i\); \(P_{dk}\) is the transmission capacity of DC \(k\); \(MIIF_{ik}\) is the interaction factor of DC \(i\) with DC \(k\), and represents a small voltage change at the converter bus \(i\) to cause a voltage change of the converter bus \(k\), as shown in equation (3).

\[MIIF_{ik} = \frac{\Delta U_k}{\Delta U_i} = \frac{Z_{ik}}{|Z_{ik}|} \]

In equation (3), \(\Delta U_i\) is the voltage change of the converter bus \(i\), \(\Delta U_k\) is the voltage change of the converter bus \(j\), \(Z_{ii}\) is the self-impedance of the bus \(i\), and \(Z_{ik}\) is the mutual impedance of the bus \(i\) and \(k\).

MSCR-based AC grid strength judgment:
- If the MSCR is greater than 3, the system is strong;
- If the MSCR is between 2 and 3, the system is weak system;
- If the MSCR is less than 2, the system is called the extremely weak.

For hierarchical infeed DC, the HSCR takes into account the influence of other DC and hierarchical DC. It is assumed that both ends of hierarchical DC are numbered as \(i\) and \(j\) respectively.

\[HSCR_i = \frac{S_{aci}}{P_{di} + \sum_{k \neq i, k \neq i} \frac{Z_{ik}}{Z_{ii}} P_{dk} + \frac{Z_{ij}}{Z_{ij}} P_{dj}} \]
In equation (4), $S_{aci}$ is the AC three-phase short-circuit capacity of the hierarchical DC terminal $i$; $P_{di}$ is the power of the hierarchical DC terminal $i$; $P_{dj}$ is the power of the hierarchical DC terminal $j$, $P_{dk}$ is the power of DC $k$ except for hierarchical DC; $Z_{ik}$, $Z_{ij}$, $Z_{ii}$, and $Z_{jj}$ are elements corresponding to the impedance matrix, respectively.

HSCR-based AC grid strength judgment:
- If the HSCR is greater than 3, the system is strong;
- If the HSCR is between 2 and 3, the system is weak;
- If the HSCR is less than 2, the system is extremely weak.

Since MIIF can only characterize the influence of DC $i$ on DC $k$, in order to characterize the interaction between two DCs, a DC coupling index $\eta$ is proposed:

$$\eta_{ij} = \sqrt{MIIF_{ij}^2 + MIIF_{ji}^2}$$  \(5\)

3. Critical section channel maintenance evaluation method suitable for double UHVDC feed grid

A process of the critical section channel maintenance evaluation method for double HVDC feed-in grid is shown in the Figure 1, and the specific steps are as follows:
- Determine the critical section of the grid;
- Calculate the MSCR (HSCR) of the two DCs after maintenance of the channel in the critical section;
- Determine whether there is a MSCR below the threshold value (MSCR for the weak AC system is 3), if it exists, go to step 4, otherwise go to step 5;
- The channel is critical. If the channel is in maintenance mode, the DC power needs to be adjusted to meet the requirement of MSCR (HSCR), and step 5 is performed;
- Calculate the coupling index between two DCs with different channel maintenance;
- The channel with the lower coupling index can reduce the double DC simultaneous commutation failure area during channel maintenance.

It should be pointed out that for hierarchical DC, usually because the electrical distance is close at both ends, when the AC system fails, the commutation failure will occur at the same time in most cases. In this paper, the node with high HSCR is selected to calculate MIIF. Nodes with a low HSCR is not considered.
4. Simulation

Taking the planned HN Power Grid as an example, the HN Power Grid forms a double feed-in pattern of HZ DC and QY DC.

- The HZ DC converter bus is in ZZ area of HN Province, and the QY DC converter bus is in ZMD area of HN Province. The critical section between the two DCs is from the central part of HN to the south section of HN. It consists of four channels, namely JH-GC, WZ-TH, WZ-XS and XF-HD channels.

- After the different channels in the critical section are maintained, MSCR of the HZ DC and the HSCR of QY DC hierarchical DC are shown in Table 1.

| No. | Maintenance Channel | HZ DC MSCR | QY DC high-end HSCR | QY DC low-end HSCR |
|-----|---------------------|------------|---------------------|--------------------|
| 1   | /                   | 5.569      | 3.534               | 4.018              |
| 2   | WZ-TH               | 5.861      | 3.878               | 4.486              |
| 3   | WZ-XS               | 6.381      | 4.672               | 4.973              |
| 4   | XF-HD               | 5.528      | 3.538               | 4.039              |
| 5   | JH-GC               | 6.411      | 4.651               | 4.943              |

- When there is no maintenance channel, the MSCR/HSCR is lower than 3 (the system with MSCR and HSCR lower than 3 is a weak system). Therefore, it is not necessary to adjust the DC power after the maintenance of any channel in the critical section of the central HN to the southern part of HN to meet the requirements of the short-circuit ratio of the receiving end.

- After the different channels in the critical section are maintained, the MIIF is shown in Table 2.

Because the low-end hierarchical DC short circuit ratio of QY DC is high, the MIIF should take the low-end into account.

| Numbering | Channel overhaul | MIIF_{12} | MIIF_{21} |
|-----------|-----------------|-----------|-----------|
| 1         | /               | 0.098     | 0.065     |
| 2         | WZ-TH           | 0.075     | 0.050     |
| 3         | WZ-XS           | 0.057     | 0.037     |
| 4         | XF-HD           | 0.052     | 0.037     |
| 5         | JH-GC           | 0.061     | 0.039     |

Note: HZ DC number is 1, QY DC low end number is 2.

- Calculating the DC coupling index of HZ DC and QY DC after maintenance of different channels.

| Numbering | Channel overhaul | \( \eta_{ij} \) |
|-----------|-----------------|----------------|
| 1         | /               | 0.118          |
| 2         | WZ-TH           | 0.090          |
| 3         | WZ-XS           | 0.068          |
| 4         | XF-HD           | 0.064          |
| 5         | JH-GC           | 0.072          |

It can be seen from Table 3 that after the XF-HD channel is maintained, the HZ DC and QY DC coupling index is the lowest, and the fault area where DC simultaneous commutation failures is caused by specific fortification failures will be reduced.

When simulating the N-1 fault of 500kV line in HN power grid, the fault area where HZ and QY DC simultaneous commutation failures is shown in Figure 2. When XF-HD channel is maintained, the fault area where DC simultaneous commutation failures is caused by N-1 fault of 500kV line is shown in Figure 3. It can be seen from Figure 2 and Figure 3 that after the maintenance of the XF-HD channel,
the area where HZ and QY DC simultaneous commutation failures is caused by N-1 fault of 500kV line decreased.

5. Conclusion

- For the dual DC feed grid, the proposed method can quantitatively evaluate the impact on the system after the critical section channel is overhauled, especially the size of the simultaneous commutation failure area.
- The DC coupling index can characterize the interaction between two DCs. The larger the dc coupling index is, the greater the interaction between the two direct current systems and the larger the failure area of commutation. The smaller the dc coupling index is, the smaller the interaction between the two direct current systems and the smaller the failure area of commutation.

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