

Preferably Receiving End's Infeed Modes for UHVDC Power Transmission

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Abstract. With unceasing increase of traditional HVDC transmission capacity, it became more and more obvious that the voltage supporting ability of receiving end power system restricts the development of HVDC power transmission, which also blocks the application of HVDC. This paper according to nodal impedance matrix, short-circuit ratios of the receiving end system under hierarchical connection mode and multi-terminal feed mode are derived. Besides, the voltage support capabilities of different modes are analyzed. The simulation was carried out and verified the feasibility and rationality of multi-terminal feed mode, which proved the UHVDC multi-terminal feed mode is helpful to increase the voltage support capability and enable the reasonable power flow distribution between 1000kV layer and 500kV layer.

1. Introduction

China has a vast territory, with an inverse distribution of primary energy and load [1]. In order to ensure sufficient electricity supply in the central and eastern regions where China's economy is developing rapidly, measures must be taken to achieve ultra-long-distance, ultra-large-capacity power transmission. UHVDC transmission has the advantages of long distance, large capacity, low energy consumption, and high stability. It is an effective way to implement the "West-East Electricity Transmission" strategy [2]-[3]. However, the traditional two-terminal direct current can realize the point-to-point DC power transmission. When the UHVDC power transmission project provides a large amount of power for the AC power grid, it will inevitably interact with the AC power grid, which will have a certain impact on the AC system.

In recent years, UHVDC transmission has made breakthrough progress in China. In the next 10 to 20 years of planning, there will be dozens of UHVDC transmission projects completed and put into operation to supply power to the East Central Load Center. Traditional HVDC transmission technology which based on LCC requires the receiving end AC grid to provide sufficient commutation voltage, and absorbs a large amount of reactive power in the course of power recovery after commutation failure occurs [4]-[6]. The multi-infeed DC will supply the receiver AC grid and bring serious problems involving security and stability. The main problem of the multi-infeed DC system is whether the receiving end network can provide strong voltage support, the voltage supporting effect of the AC grid on the DC system depends on the relative size between the AC system and the DC transmission capacity. That is short-circuit ratio index [7]-[8]. Based on the discussion of multi-infeed system strength standards, the literature [9] innovatively proposed UHVDC access to the AC grid using a hierarchical access method and studied multi-feedback in a hierarchical access mode about the short circuit ratio study. According to the national grid plan, the newly-built ± 800 kV Ximeng-Taizhou and ± 1100 kV Inverter Stations of UHVDC power transmission lines in Inner Mongolia Hulunbeier-Anhui-Fujian two loops are proposed to use hierarchical access to 1000kV and 500kV AC grids.



Reference [10] proposed two methods of multi-terminal single-layer feeding and multi-level hierarchical feeding of receiving end of HVDC transmission. By comparing the short-circuit ratio and power transmission curve of the receiving end system under different feeding modes, the advantages of multi-end feeding were verified [11]. The single feed end and multiple distributed receiver HVDC multi-terminal feed connection methods can improve the line utilization rate and improve the problems of commutation failure in the traditional two-end HVDC transmission systems [12]. This article starts with the analysis of multi-terminal feed-in DC, discusses the advantages and disadvantages of the receiver's layered access and multi-feeds, and uses the $\pm 800\text{kV}$ Ximeng-Taizhou UHVDC power transmission project as a background to build a simulation model to verify the feasibility of multi-terminal feeding.

2. Mathematical model and analysis of HVDC hierarchical access scheme

2.1 UHVDC single-layer access and hierarchical access methods

The AC side of the UHVDC power transmission inverter station has only one voltage level for single-layer access, and two voltage levels for layered access. Take the 800kV Ximeng-Taizhou UHVDC transmission project as an example. The two access methods are shown in Figure 1 and Figure 2, respectively.

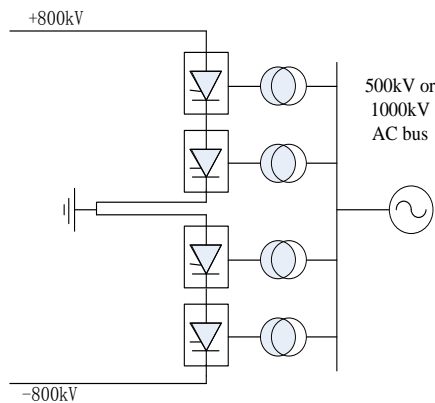


Figure 1. UHVDC single-layer connection mode to AC system

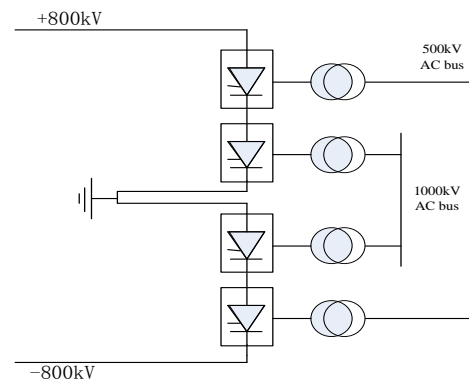


Figure 2. UHVDC hierarchical mode to AC system

2.2 Multi-infeed short circuit ratio analysis of UHVDC

The equivalent diagram of a multi-infeed DC system is shown in Fig.3. There is a link impedance z_{ij} between the DC system i and j , so when a disturbance causes a voltage change ΔU_i on the commutation bus i , the voltage change ΔU_j at the commutation bus j will also be caused. Multi-infeed short-circuit ratios are often used to calculate and analyze the AC system's voltage support capability for multi-infeed DC system.

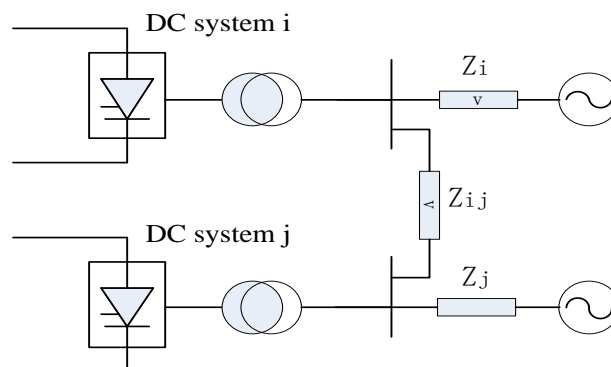


Figure 3. Multi-infeed HVDC equivalent system

The multi-infeed short-circuit ratio calculation formula proposed by CIGRE Multi-infeed DC Working Group in 2007 is as follows:

$$MISCR_i = \frac{S_{aci}}{P_{di} + \sum_{j=1, j \neq i}^n P_{dj} \frac{\Delta U_j}{\Delta U_i}} \quad (1)$$

$$MISCR_i = \frac{U_{iN}^2}{|Z_{eqii}| P_{di} + \sum_{j=1, j \neq i}^n P_{dj} |Z_{eqij}|} \quad (2)$$

If $U_{iN}=1$, then there is

$$MISCR_i = \frac{1}{|Z_{eqii}| P_{di} + \sum_{j=1, j \neq i}^n |Z_{eqij}| P_{dj}} \quad (3)$$

In the formula: each physical quantity is the standard value; $MISCR_i$ is the multi-infeed short-circuit ratio corresponding to the i -th DC system; S_{aci} is the short-circuit capacity of the AC side of the i -th commutation bus; U_{iN} is the i -th commutation bus. The rated voltage on Z_{eqii} is the self-impedance corresponding to the i -th commutation bus in the equivalent impedance matrix; Z_{eqii} is the mutual impedance between the i -th commutation bus and the j -th commutation bus; P_{di} is the rated power of i -th DC system; P_{dj} is the rated power of the j -th DC system.

2.3 Analysis of multi-infeed short circuit ratio under layered access of UHVDC

The ± 800 kV Ximeng-Taizhou UHVDC transmission project adopts a layered access method on the inverter side, which is equivalent to dividing a single-circuit DC transmission line into two DC lines with half capacity and connecting 500kV and 1000kV converter busbars respectively. Then formula (3) becomes:

$$MISCR_i = \frac{1}{\frac{1}{2} |Z_{eqii}| P_d + \sum_{j=1, j \neq i}^n \frac{1}{2} |Z_{eqij}| P_d} \quad (4)$$

Analysis method of HVDC multi-infeed can be referred to multi-infeed short-circuit ratio calculation of UHVDC with layered access. Points to note:

(1) Multiple feed-in short-circuit ratios are calculated for each busbar that is accessed hierarchically. The n hierarchically connected converter stations need to calculate the multi-infeed short-circuit ratio of $2n$ commutation buses.

(2) Retain the busbars of the converter stations that are layered into the AC grid, calculate the system-wide node admittance matrix, and form the Thevenin's equivalent network.

From the equivalent network in Figure 3, the node admittance matrix is

$$Y = \begin{pmatrix} \frac{1}{Z_i} + \frac{1}{Z_{ij}} & -\frac{1}{Z_{ij}} \\ -\frac{1}{Z_{ij}} & \frac{1}{Z_j} + \frac{1}{Z_{ij}} \end{pmatrix} \quad (5)$$

Then find the inverse node impedance matrix as

$$Z = \begin{pmatrix} \frac{z_i z_{ij} + z_i z_j}{z_i + z_{ij} + z_j} & \frac{z_i z_j}{z_i + z_{ij} + z_j} \\ \frac{z_i z_j}{z_i + z_{ij} + z_j} & \frac{z_j z_{ij} + z_i z_j}{z_i + z_{ij} + z_j} \end{pmatrix} \quad (6)$$

$$\begin{cases} Z_{eqii} = \frac{z_i z_{ij} + z_i z_j}{z_i + z_{ij} + z_j} \\ Z_{eqij} = Z_{eqji} = \frac{z_i z_j}{z_i + z_{ij} + z_j} \\ Z_{eqjj} = \frac{z_j z_{ij} + z_i z_j}{z_i + z_{ij} + z_j} \end{cases} \quad (7)$$

Where z_i and z_j are the 1000 kV and 500 kV plane equivalent impedances; z_{eqii} and z_{eqjj} are the self-impedances of the 1000 kV and 500 kV commutation buses respectively; z_{eqij} is the mutual impedance between the two commutation buses.

From formula (7), we know $Z_{eqii} > Z_{eqjj}$. Therefore, the short-circuit ratios of the 1000kV and 500kV busbars in the layered access mode are all higher than those of the 1000kV and 500kV busbars in the single-layer access mode. After calculation, the short-circuit ratio of the direct access 1000kV program is 4.08; the short-circuit ratio of the direct access 500kV program is 3.62; the short-circuit ratio of the 1000/500kV scheme of hierarchical access is 5.42/5.43.

3. Stability analysis of multi-end feeding of UHVDC

HVDC transmission multi-feed refers to a UHVDC transmission line fed into the receiver power grid through a number of converter stations. It can be subdivided into multi-end single-layer feeding mode and multi-terminal hierarchical feeding mode. Multi-terminal single-layer feeding mode means that a tributary line is fed to the receiver voltage level through two or more converter stations at the same. Multi-tiered hierarchical feeding means that a branch line is fed to different voltage levels through two or more converter stations. As shown in Figure 4. Connect the transformer to the Π -type equivalent. The simplified equivalent network is shown in Figure 5. The node number sequence is i, j, k .

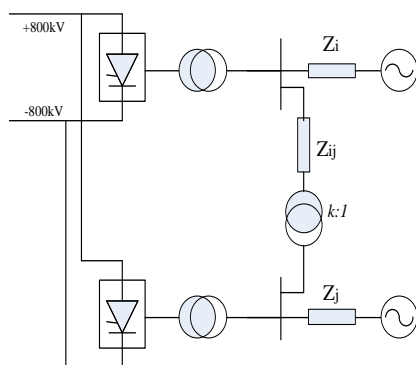


Figure 4. Multi-infeed hierarchical HVDC equivalent system

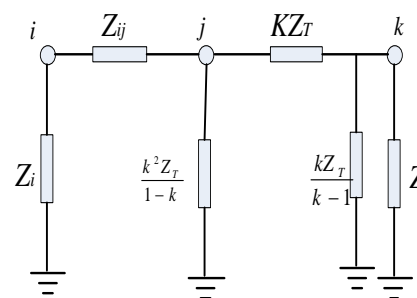


Figure 5. Multi-infeed hierarchical HVDC equivalent node network

From Figure 5, we can get the node admittance matrix:

$$Y_0 = \begin{pmatrix} \frac{1}{z_i} + \frac{1}{z_{ij}} & 0 & -\frac{1}{z_{ij}} \\ 0 & \frac{1}{z_j} + \frac{k-1}{kz_T} + \frac{1}{kz_T} & -\frac{1}{kz_T} \\ -\frac{1}{z_{ij}} & -\frac{1}{kz_T} & \frac{1}{z_{ij}} + \frac{k-1}{kz_T} + \frac{1}{kz_T} \end{pmatrix} \quad (8)$$

Block the matrix, use the node elimination formula, eliminate the extraneous node k , get the admittance matrix of node i, j , then get the impedance matrix of the node i, j .

$$Y = \begin{pmatrix} \frac{1}{z_i} + \frac{1}{k^2 z_T + z_{ij}} & -\frac{k}{k^2 z_T + z_{ij}} \\ -\frac{k}{k^2 z_T + z_{ij}} & \frac{1}{z_j} + \frac{1}{k^2 z_T + z_{ij}} \end{pmatrix} \quad (9)$$

$$Z = \begin{pmatrix} \frac{z_i(z_{ij} + k^2 z_j + k^2 z_T)}{z_i + z_{ij} + k^2(z_j + z_T)} & \frac{kz_i z_j}{z_i + z_{ij} + k^2(z_j + z_T)} \\ \frac{kz_i z_j}{z_i + z_{ij} + k^2(z_j + z_T)} & \frac{z_j(z_{ij} + z_i + k^2 z_T)}{z_i + z_{ij} + k^2(z_j + z_T)} \end{pmatrix} \quad (10)$$

We can calculate the short-circuit ratio in the multi-layered feeding mode when substituting the result into equation (2).

4. Simulation and result

The simulation model is based on the Ximeng-Taizhou UHVDC power transmission project. The rated operating voltage on the AC side of the rectifier station is 530kV, the rated operating voltage on the AC side of the inverter station is 520kV, and the rated operating voltage on the AC side of the inverter station is 1050kV. The rated voltage of the DC transmission line is ± 800 kV, the rated current is 6.25kA, and the rated transmission power is 10000MW.

Control strategy: The rectifier side maintains the reference value of the direct current by the direct current of the rectifier side by controlling the trigger angle α of the converter. With constant power control mode, the DC current reference value is determined as follows: $I_d = P_{ref}/U_d$. where U_d is the line side of the rectifier side smoothing reactor

By controlling the rectifier-side transformer taps such that α is maintained within the range of $\alpha_N \pm 2.5^\circ$, as long as the firing angle is within this range, the tap change tap will not act to bring the firing angle closer to the rated value. The side extinction angle γ of the inverter side is kept constant, and the DC voltage of the rectifier side is controlled by adjusting the inverter side commutation tap. When the inverter side tap is adjusted, the DC voltage changes, and the DC current on the rectifier side will change to make the DC power constant. For example, when the DC voltage U_d decreases by 0.625%, the DC current will increase by 0.625% to maintain the DC power unchanged.

The waveforms of AC voltage, DC voltage and current, active and reactive power, and trigger angle during steady-state operation of the rectifier station are shown in Figs. 6, 7, 8, and 9

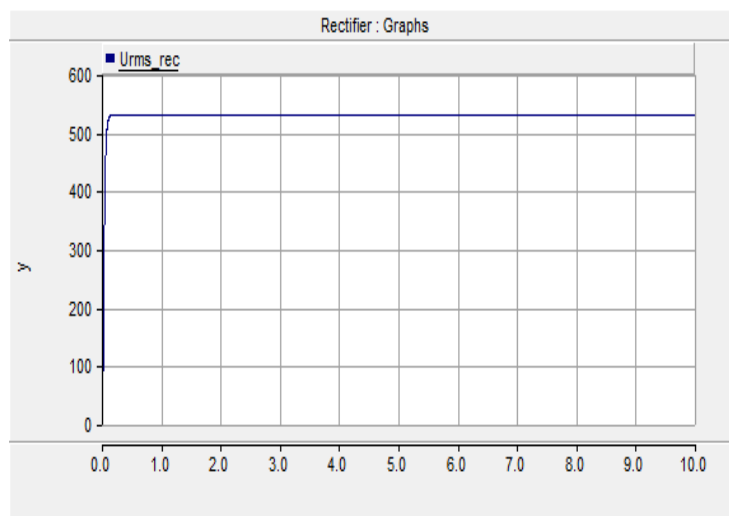


Figure 6. Rectifier steady-state operation AC voltage waveform

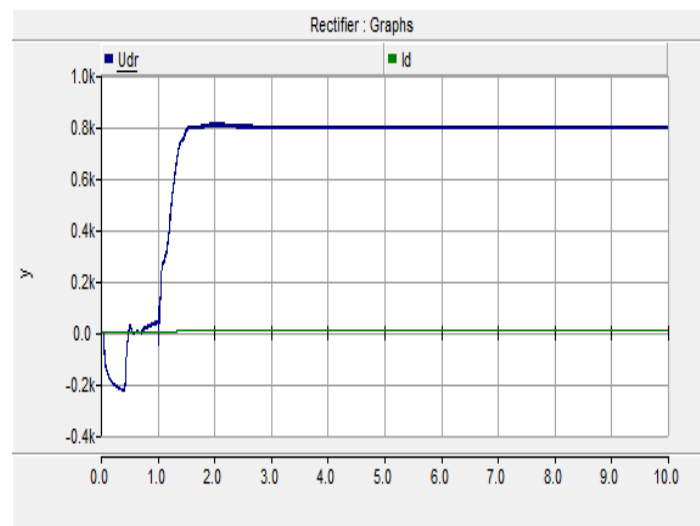


Figure 7. Rectifier steady-state operation DC voltage and current waveform

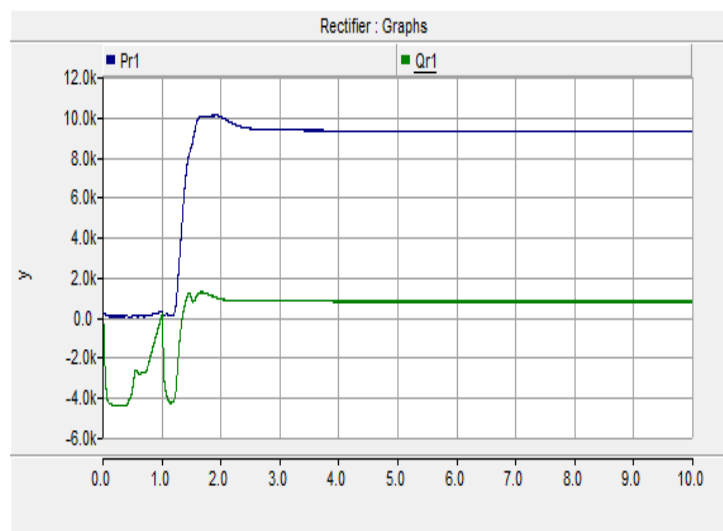


Figure 8. Rectifier steady-state operation active power and reactive power waveform.

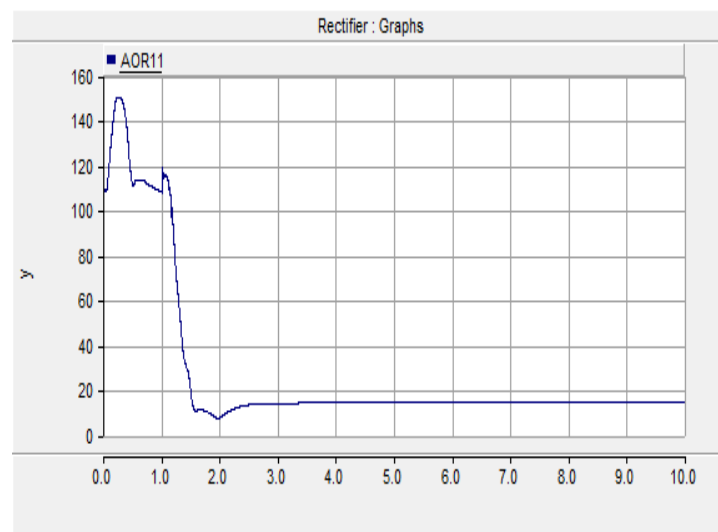


Figure 9. Rectifier steady-state operation firing angle waveform

It is calculated that the ratio of multiple feed-in short-circuits for the 1000kV commutation bus and the 500kV commutation bus under this feed-in mode is 5.18 and 4.65 respectively, compared to the short-circuit ratio of 4.08 and the direct access 500kV scheme for direct access to the 1000kV scheme. Short circuit is much higher than 3.62.

5. Conclusion

The multi-infeed short-circuit ratio calculation method proposed by CIGRE can deduce the short-circuit ratio of UHVDC layered access mode and UHVDC multi-terminal feeding mode. The short-circuit ratio of the 1000kV and 500kV busbars in the two methods of UHVDC layered access and UHVDC multi-terminal feeding is higher than that of the 1000kV and 500kV busbars in the single-layer access mode, which can cause the system to have a large short circuit as a whole. Ratio and voltage support capabilities. Hierarchical access and multi-terminal infeed can improve the system voltage support capability, reduce the risk of inverter station commutation failure, and have important significance for promoting the coordinated development of AC and DC power grids. It is also important for UHVDC development, DC networking, and power grid planning.

6. References

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Acknowledgments

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