

The judgement of simultaneous commutation failure in HVDC about hierarchical connection to AC grid

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Abstract. The hierarchical connection to AC grid at inverter sides in UHVDC has been taken in several projects. This paper introduced the frame of the connection mode in hierarchical access system and compared it with the traditional one at the case of HVDC-Cigre. Then the criterion of commutation failure according to the same valves current was deduced. In order to verify the accuracy of the criterion, this paper used PSD-BPA (Bonneville Power Administration) to simulate the setting voltage drop in the East China power grid and certified the correctness of the formula.

1 Introduction

China has gradually formed a pattern of large-scale power corridor transmission from west to East with the construction of UHVDC and matched energy base. It also makes voltage support capability uneasy for the poor AC grid and has the difficulty to distribute amount of energy^[1]. By 2018, the power of the transmission section will reach 5.5×10^7 kW, so the situations will be even worse. In order to alleviate this situation, Chinese scholars first proposed hierarchical connection to AC grid structure at Inverter side where the high voltage 12 pulsation valves access to 500kV AC network while the low voltage valves 12 pulsation valves access to 1000kV AC network to improve the voltage tenability. The layered inverter is connected to two different AC networks which the 500kV grid connect to the local network and the other grid is 1000kV (extra-high voltage grid to delivery). High and low valves group work independently so the control mode have more flexibility^[2]. Compared with the pole access mode, not only is the control strategy more complicated, but also the strong coupling of the current and voltage. Whether the complex electrical coupling can lead to the commutation failure of the other stage converter valves is worth studying.

This paper introduced the definition of hierarchical access interaction factor, and the formulas for determining the commutation failure of high and low pressure valves groups is derived out according to the characteristics of current coupling in high and low valves groups. Then established a hierarchical access model based on Cigre and compared the simulation results with Cigre. At last the simulation at East China's power grid verified the accuracy of the criterion.

2 Hierarchical connection to AC grid mode of UHVDC transmission

As figure 1 shows, high and low voltage valves connect to an AC grid in rectifier side, while the inverter access to two different AC power grids. The P_r and Q_r represent active and reactive power at



the sending end. P_{i1} and Q_{i1} are active and reactive power at high pressure valves groups in rectifier side, and P_{i2} 、 Q_{i2} are low pressure valve groups. U_{dr} 、 U_{di} 、 U_{di1} 、 U_{di2} are the output DC voltage of rectifier, input DC voltage of inverter and valve group voltage. Where I_d is direct current, and R_d is line resistance [3].

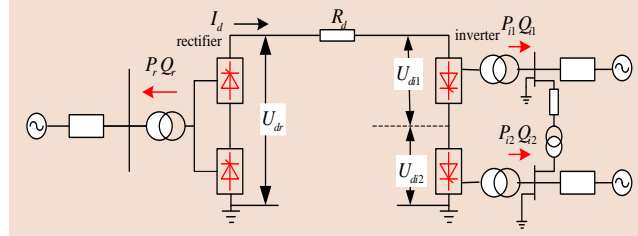


Fig.1 Legend of simplified single-pole model of HVDC hierarchical structure
According the figure 1, we can list the DC voltage and power equation below.

$$\begin{cases} U_{dr} = I_d R_d + (U_{di1} + U_{di2}) \\ P_{dr} = U_{dr} I_d \\ P_i = P_{i1} + P_{i2} = (U_{di1} + U_{di2}) I_d \\ P_{dr} = P_{i1} + P_{i2} + I_d^2 R_d \end{cases} \quad (1)$$

The voltage at both ends of the converter can be expressed as:

$$\begin{cases} U_{dr} = \frac{3\sqrt{2}}{\pi} B_1 K_r E_1 \cos \alpha - \frac{3}{\pi} B_1 X_r I_d \\ U_{di1} = \frac{3\sqrt{2}}{\pi} B_2 K_{i1} E_{21} \cos \gamma_{i1} - \frac{3}{\pi} B_2 X_{i1} I_d \\ U_{di2} = \frac{3\sqrt{2}}{\pi} B_2 K_{i2} E_{22} \cos \gamma_{i2} - \frac{3}{\pi} B_2 X_{i2} I_d \end{cases} \quad (2)$$

The E_1 is on behalf of bus voltage of sending converter station, while E_{21} 、 E_{22} represent the 500kV/1000kV AC grid voltage connected to the inverter side. The $B_1=4$, $B_2=2$ are on behalf of the six operated valve number. K_r 、 K_{i1} 、 K_{i2} are ratio of transformer at rectifier and inverter. X_r 、 X_{i1} 、 X_{i2} are equivalent commutation reactance. The angle of α is trigger angle of the rectifier. γ_{i1} 、 γ_{i2} are extinction angle at the inverter. As shown above the commutation source of the converter valve is provided by the AC bus voltage and the coupling of the valves of the inverter are directly reflected by the voltage. The article (4) defines the mutual influence by the end of two hierarchical connection to AC grid (hierarchical connection interaction for factor, HCIF): The interaction factor is one converter AC bus voltage's change rate, when the other converter bus for input three-phase reactor makes the bus voltage drop 1 percent.

$$HCIF_{ji} = \frac{\Delta U_j}{1\% U_{i0}} \quad (3)$$

The U_{i0} is the High (low) converter bus voltage before putting in reactor, while ΔU_j is the change value of low end (high end) commutation bus.

3 Influence of AC / DC coupling on commutation failure

In the literature of the article 5, the definition of the interaction factors have such equation:

$$HCIF_{ji} = \frac{\Delta U_j}{1\% U_{i0}} = \left| \frac{Z_{ij}}{Z_{ii}} \right| \quad (4)$$

The Z_{ij} represents mutual impedance between I and J, and Z_{ii} is the self-impedance bus of I. From the equation we can know the equivalent parameter ratio of hierarchical access interaction factor is

determined by the inverter side AC power network, not the DC operating parameters. So the parameters can be used to analysis the influence of DC commutation failure in the form of hierarchical access.

3.1 analysis and criterion of commutation failure

Trigger angle is normally at 164 degrees at inverter, if the voltage become positive when the current is not reduced to zero so at that time the free electron is still exist, the valve commutation failure will occur. It always occurs at the current rise which lead to the electron ionization time being longer and the extinction angle being decreased. According to the engineering experience, it is generally considered that the commutation failure occurs when the arc extinction angle is less than 7 degrees.

3.2 Equations

We can get the basic formula from book 6:

$$\gamma = \arccos\left(\frac{\sqrt{2}nI_d X_L}{U_L} + \cos \beta\right) \quad (5)$$

Where β is the trigger angle ($\beta = 180^\circ - \alpha$).

Assume that the normal operation bus voltage corresponding with high voltage and low voltage valve groups are \dot{U}_{L10} and \dot{U}_{L20} . According to the formula (4), we can obtain the instantaneous voltage drop of the low valves bus ($\Delta\dot{U}_{L2}$) when a fault causes the transient voltage drop of the high values bus.

$$\Delta\dot{U}_{L2} = \text{HCIF}_{21} \Delta U_{L1} \frac{\dot{U}_{L2N}}{\dot{U}_{L1N}} \quad (6)$$

Low voltage of converter valve bus comes to \dot{U}_{L2} :

$$\dot{U}_{L2} = \dot{U}_{L20} + \Delta\dot{U}_{L2} = \dot{U}_{L20} + \text{HCIF}_{21} \Delta U_{L1} \frac{\dot{U}_{L2N}}{\dot{U}_{L1N}} \quad (7)$$

\dot{U}_{L1N} 、 \dot{U}_{L2N} respective the rating voltage of the high and low valves group of the converter. Where \dot{U}_{L20} is the initial bus voltage of the low voltage converter valves. The sum of the effective value of AC voltage which inverter bears is as (8) shown.

$$\dot{U}_L = \dot{U}_{L1} + \dot{U}_{L2} \quad (8)$$

If the DC control system is not in operation (because time delay) and the DC voltage from the rectifier side has not changed yet, the DC voltage control system has the following characteristics:

$$\dot{U}_{di} = V_{d0} \cos \beta_0 = \frac{3\sqrt{2}\dot{U}_L}{\pi} \cos \beta_0 = \frac{3\sqrt{2}\dot{U}_L}{\pi} \cos \beta_0 \quad (9)$$

Therefore, when considering the response of the control system, the maximum instantaneous current flowing through the DC line and the inverter side converter valve will raise to \dot{I}_{max} .

$$\dot{I}_{max} = \frac{\dot{U}_{dr} - \dot{U}_{di}}{R_L} \quad (10)$$

Where the \dot{U}_{dr} is DC voltage of the rectifier. According to the (5)、(8)、(9) and (10), we can obtain the expression of arc extinguishing angle of high and low pressure valve group of the inverter station.

$$\gamma_{im} = \arccos\left(\frac{\sqrt{2}n\dot{U}_{dr} - \frac{3\sqrt{2}\cos\beta_0\dot{U}_\tau}{\pi}}{\dot{U}_\tau}\right) \quad (11)$$

Where $\dot{U}_\tau = \dot{U}_{L10} + \dot{U}_{L20} + \Delta\dot{U}_{L1} + \text{HCIF}_{21} \Delta\dot{U}_{L1} \frac{\dot{U}_{L2N}}{\dot{U}_{L1N}}$;

Where γ_{im} is the max of γ . Inverter will occur commutation failure when γ is less than 7 degrees. From the formula we can get the critical voltage shown below.

$$\Delta\dot{U}_{L1}' = \frac{\frac{\sqrt{2}n\dot{U}_{dr}}{\cos 7^\circ + 3\sqrt{2}\cos\beta_0} - \dot{U}_{L10} - \dot{U}_{L20}}{1 + \text{HCIF}_{21} \frac{\dot{U}_{L2N}}{\dot{U}_{L1N}}} \quad (12)$$

The inverter will occur commutation failure when $\Delta\dot{U}_{L1}$ is larger than $\Delta\dot{U}_{L1}'$. We can get the conclusion that hierarchical access structure is stability than traditional structure from the formula above.

4 Simulations

4.1 The Cigre case of HVDC

To certify the formula above, this article modified the model of Cigre to equivalent hierarchical access system as the same capacity and parameters with Cigre sampled in figure 2.

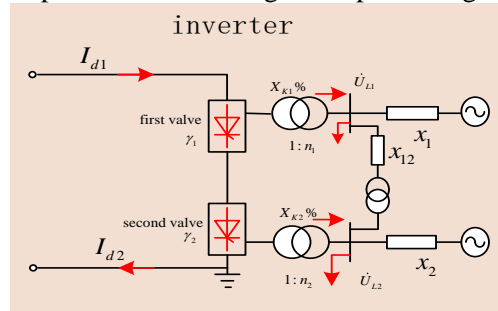
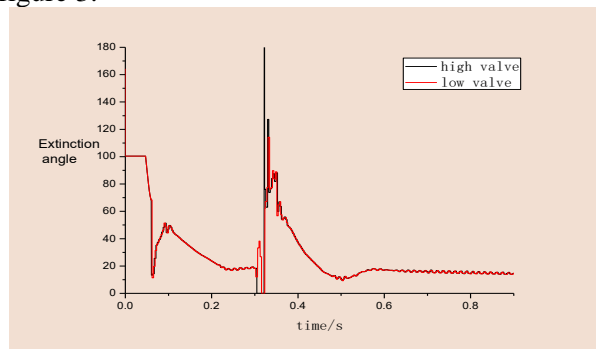
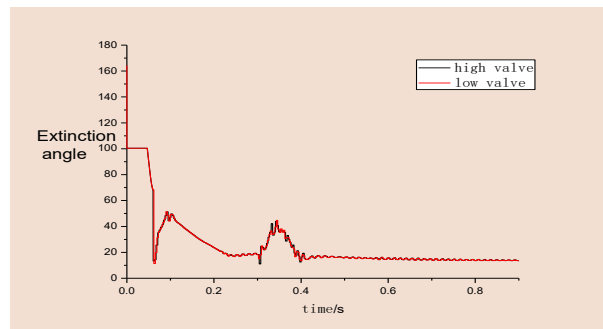


Fig. 2 Simplified equivalent circuit of Receive-side

In two model simulations, the same three-phase grounding fault is added at 0.3 second and keep 0.1 second, The result curve of the extinction angle of the high and low voltage converter valve on the inverter side is shown in figure 3.



(a) Arc extinction angle of Cigre



(b) Arc extinction angle of hierarchical access

Fig. 3 Arc extinction angle of inverter side converter fault

When the valves start to unblock, the extinction angle starting from 100 degrees, then it gradually stabilized at 18 degrees. We add fault at 0.3 second and at that moment the control system has not played a role, the instantaneous voltage reduce make current increases rapidly, which lead extinction angle of the inverter decreased quickly too. When the control system worked, it forced the extinction angle to 17° which avoid continuous commutation failure.

From the Fig. 3 above we can see from (a) that the minimum values of the two arc extinction angles have been reached 0 degrees, so the commutation failure occurs, while the minimum arc extinction angle of the hierarchical connection to AC grid of (b) graph is greater than (a) which escaped the commutation failure. The above analysis shows us that hierarchical access has a higher level of stability.

4.2 Actual large power grid simulation

In order to verify the correctness of the above theory, the PSD-BPA electromechanical transient simulation software was used to the simulation in the East China Power Grid in 2017 as shown in figure 4.

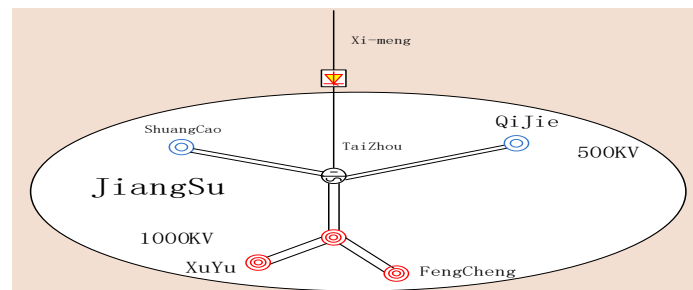
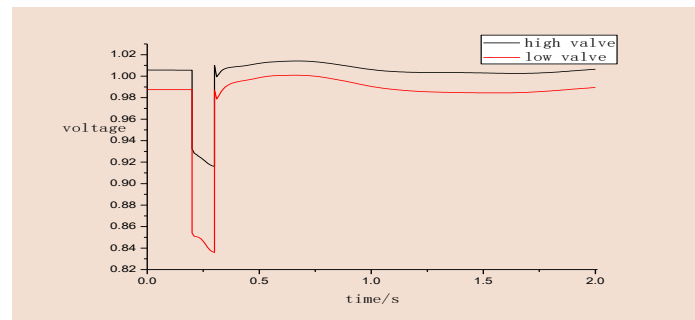


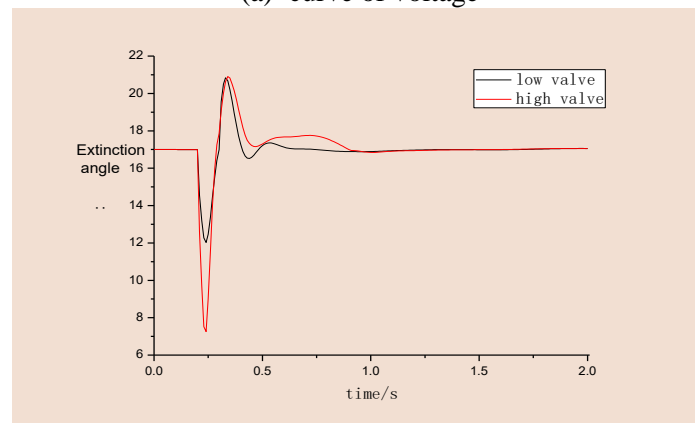
Fig. 4 Schematic of the hierarchical attach to AC system for $\pm 800\text{kV}$ Xilinhaote-Taizhou UHVDC in geographical

The UHVDC bipolar layered Ximeng-Taizhou HVDC project $\pm 800\text{kV}/10\,000\text{ MW}$ power system of receiving is shown in Figure 4. We take UHVDC Current steady state Model in transient stability program. From the system parameters we can see that the system's 525 bus voltage for the 1050 bus voltage stratification access interaction factor HCIF is 0.54. Assuming that the system is operating in the rated parameter state, the equation (12) can be calculated as 0.37(pu). We simulate the inverter side of the high-pressure valve converter bus voltage drop by add the three-phase grounding near-end fault between Guo Taihuan and Su Shuang grass. We obtained Figure 5 and Figure 6 when the ground resistance is 0.008 and 0.003 for a duration of 0.1 s, respectively.

As can be seen from Figure 5, when the grounding resistance is 0.008, the voltage corresponding to the bus voltage is 0.85 (pu),

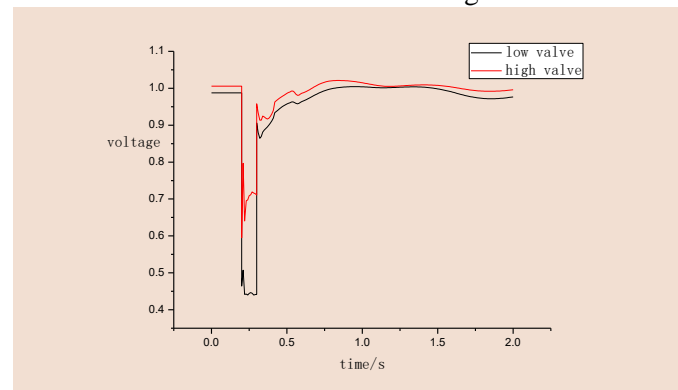


(a) curve of voltage

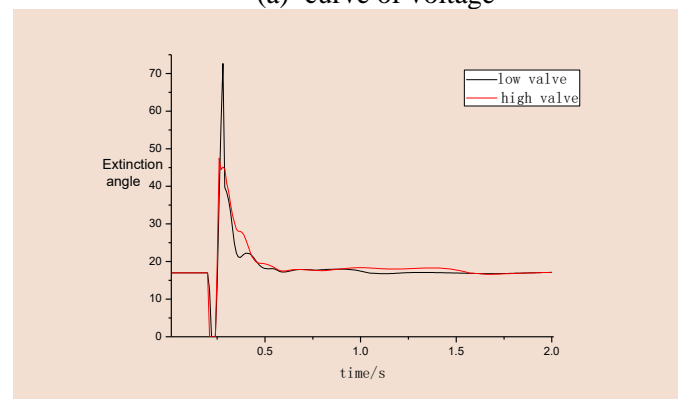


(b) curve of extinction angle

Fig. 5 DC simulation waveform when the ground resistance is 0.008



(a) curve of voltage



(b) curve of extinction angle

Fig. 6 DC simulation waveform when the ground resistance is 0.003

5 Conclusion

Obviously, the simulation above verifies the correctness of the formula deduced in the hierarchical access mode. We can use the hierarchical access interaction factor to judge the commutation failure of the high and low pressure valve group at the same time. The impact resistance of the hierarchical connection to AC grid method is higher than that of the traditional multi-access mode. And the higher the interaction factor of the stratified access, the greater possibility of commutation failure in the high and low pressure valve group is when the ground fault of a commutation side of the inverter occurs. Moreover, in order to improve the stability of the proposed DC transmission we can increase the electrical distance between two AC power grids at Inverter side to reduce the HCIF.

References

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