Analysis and Research on Power Systems Computer Aided Design for Yindong DC Transmission System

Zhao xiaoxiao 1,a, yun yuxin 3,b
1 Technical College Branch of State Grid Corporation of China, Jinan, China
3 Shandong Electric Power Research Institute, Jinan, 250002, China
aE-mail: laughnet@163.com. bE-mail: yuxin_yun@126.com.

Abstract: The AC equivalent (Shandong power grid) model of inverter side is established by electromagnetic transient simulation method, and the real data of Yindong transmission frame of HVDC is set in PSCAD model. Shandong power grid has set up different centralized faults. Asymmetric circuit accident are the most serious among them. Based on this analysis, we come to the conclusion that the fault of Shandong electric power AC system has a greater impact on Yindong DC transmission system, which provides important guidance for the reliable operation of Yindong HVDC transmission model in the future. We think it has better theoretical reference value.

1. Introduction
The transmission mode of HVDC system is long distance, high power, and has been widely used. The key project of DC transmission in Shandong power grid adopts HVDC transmission system. Rated DC voltage of Yindong DC transmission system is ±660kV, which is lower than that of other ±800kV DC transmission projects. But we all know that the ±800kV DC transmission project adopts the monopole double 12 pulse valve model, while the Yindong DC transmission system is the single 12 pulse converter valve system. It can be compatible of ±500kV DC system, and the power of fluid and insulation level of valve are higher than ±800kV design value. Therefore, we can maintain Yindong ±660kV DC model, it will be more troublesome and will face more complex technical problems. The design of Yindong ±660kV DC transmission building station adopts inverter mode. Special characteristics of inverter station is mainly due to the high working pressure. When the inverter can not be commutation, it is an inevitable problem. Voltage drop of commutating bus may cause commutation failure. Then, the result is a interruption of DC power supply [1]. The transient voltage drop is related to the fault time, fault location and fault type of the network, which directly affects the performance of the DC system. Therefore, it is useful for us to be familiar with the direct-current transport characteristics in different situations. In addition to system detection, technical control and repair, we must also consider the power grid Department [2]. In this paper, after studying the engineering practice, the HVDC transmission network on Yindong line is established, and the simulation system is established by using the electromagnetic transient simulation method [3-5]. We flexibly use PSCAD software to build the influence of many faults in Shandong power grid on direct-current transmission system, which is of great help to the operation study of direct-current system.
2. Model establishment for Yindong DC transmission system

The main factors that affect the DC system model are the primary system and control system. Figure 1 shows the structure of Yindong ±660kV DC transmission system, and Figure 2 shows the equivalent formula.

![DC switching field and grounding electrode fault system structure of Yindong ±660kV high-voltage direct current transmission system](image)

**Fig. 1** DC switching field and grounding electrode fault system structure of Yindong ±660kV high-voltage direct current transmission system

![Equivalent circuit of Yindong DC transmission system](image)

**Fig. 2** Equivalent circuit of Yindong DC transmission system

Voi and VoJ described in Fig. 2 are the voltages with AC properties on Rectifier and inverter of the RMS respectively. What you can know is that $\alpha$ and $\beta$ are the angle of trigger delay on the rectifier side and the angle of trigger advance on the inverter side. In addition, RCI and RCJ are DC resistance converter transformer and smoothing reactor, rectifier and inverter losses.

By analyzing the characteristics and differences of main connection modes, Yindong HVDC transmission system mainly includes two types: Bipolar grounding and unipolar grounding. Through analysis and comparison, bipolar operation is more common, while unipolar operation is rarely used. Figure 2 is the equivalent circuit.

We can see from Fig. 2 that the DC transmission system equation under steady-state operation equal is:

$$V_{oi}\cos\alpha = (R_{ci} + R_{dc} + R_{cj})I_d + V_{oj}\cos\beta$$  \hspace{1cm} (1)

From the above equation, the DC current can be calculated:

$$I_d = \frac{V_{oi}\cos\alpha - V_{oj}\cos\beta}{R_{ci} + R_{dc} + R_{cj}}$$  \hspace{1cm} (2)

DC voltage $V_{oi}$, $V_{oj}$ can be described as:

$$V_{oi} = V_{oi}\cos\alpha - R_{cj}I_d$$  \hspace{1cm} (3)
$$V_{oj} = V_{oj}\cos\beta + R_{cj}I_d$$ \hspace{1cm} (4)

It is not difficult to calculate DC transmission power:

$$P_{di} = V_{di}I_d$$  \hspace{1cm} (5)
$$P_{dj} = V_{dj}I_d$$  \hspace{1cm} (6)

The control form of rectifier and inverter determines the mode of direct-current transmission. Figure 3 shows the control mode of Yindong HVDC system. In general, The rectifier is in continuous current...
operation. In direct-current system, AREVA converter valve is used, so the extinction angle can not be measured, so the modified predictive extinction angle control is used in the inverter side. Rectifier side and inverter side are equipped with low voltage limit (VDCOL) control [6]. In this control combination, the control function of the direct-current system is illustrated in detail in Fig. 3.

![Fig.3](image)

**Fig.3 Control characteristics of constant \(I_d\) on the rectifier side and the predicted \(\gamma\) on the variable frequency side**

Figure 3 depicts the characteristics of the rectifier side corresponding to the curve A-D. AB is the minimum trigger angle, BC is the constant current control, and CD is the current limiting area. The other E-I curve corresponds to the inverter side.

It can be said that the standard points is p, which is the similarities of BC and GH. This tells me that in this case, the rectify case is set to steady current control mode \((\text{trigger angle}) \ \alpha\); The inverter is set to predictive correction extinction angle control mode \((\gamma \text{ Constant})\). The rectifier control angle maintains DC current \(I_d\); Let the extinction angle of the inverter \(\gamma\) keep the valve unchanged to ensure that the valve will not reopen to make the commutation unsuccessful. We do this by setting the trigger angle of the inverter.

As we know, the invert point of Yindong DC system adapted the optimized predictive extinction angle control, which is unlike the previous stable extinction angle control. See the following formula Description:

\[
\beta = \arccos\left(\cos \gamma - \sqrt{2} I_d X_{T}/E_n\right)
\]

In the formula, \(\beta\) is the leading trigger angle of the inverter side, \(\gamma\) is the measured extinction angle of the inverter side, \(I_d\) is the direct-current current, \(X_T\) is the reactor in inverter, and \(E_n\) is the inverter voltage value side unloading line.

This kind of control is usually not good for the stability of the system. The control curve of the inverter is a positive slope line (Fig. 3, GH). In the transient case, when \(I_d\) increases due to fluctuation, the control will decrease \(\beta\). When the inverter side voltage is increased, the direct-current current \(I_d\) becomes smaller and returns to the steady-state working point. Moreover, due to the interference, the \(I_d\) becomes smaller and the control angle increases \(\beta\) to reduce the inverter side voltage and increase the direct-current current. The modified predictive extinction angle control is derived from the following equation:

\[
\beta = \arccos\left(\cos \gamma - 6 X_{T} I_d / \pi E_n + K(I_0 - I_d)\right)
\]

What is described in the equation \(\gamma\) is the rated inverter is 17° in Yindong direct-current system. K is the correction factor and \(I_0\) is the reference value of the direct-current current supplied.

Changed measurement vanishing angle has the advantages of maintaining a constant extinction angle and avoiding excessive extinction angle, which will increase the reactive power of the converter.
3. Equivalence analysis of Shandong Power Grid

3.1 Equivalence method
Simulation dynamic equivalence method is used in Shandong power grid. Its main idea is to classify the depends on the voltage. The dynamic characteristics of high-power AC / direct-current power system are mainly about the system strength of access layer of high power DC circuit and the dynamic performances of power grid. The power grid is limited by the strength of 500kV power grid, and the voltage level of 220kV or below is meaningful. The 500kV points shown in Fig4.

The following conditions should be met before and after system equivalence:

1) The total capacity and output of the generator need to remain unchanged before and after equivalence.

2) Before and after equivalence, the short-circuit current of each bus in the main power grid shall be maintained.

3) The tidal current remains unchanged before and after equivalence.

The dynamic equivalent subsystems to be retained include:

1) 500kV backbone network of the system.
2) Detailed DC lines.
3) A communication channel operating in parallel with a DC line.
4) Generators directly connected to the main grid.

3.2 Equivalence check
We take the 500 kV bus node in Shandong Province as an example. It is verified by Shandong power grid node model [12-14]. Several power plants in Shandong are directly connected to Wenshang 500kV network. Through the analysis of active power and output capacity of the two generators, the power of the active and reactive generators directly connected to the 500 kV Bus in Wenshang is calculated.

In the same way, we calculate the active power and reactive power output of similar buses. These conventional data are used to ensure that the power flow remains constant. The test results are shown in Table 1.

A three phase short-circuit fault occurred on the 500 kV Bus in Wenshang, and the fault was eliminated after 0.1 second, and the simulation lasted for 5 seconds. The dynamic response curves of original system and similar model are shown in Figure 6. Wenshang 500kV voltage amplitude bus node and generator power angle response curve are directly connected with 500kV bus.

| Bus Name   | Voltage Level | Positive Sequence Current Before Equivalence | Positive Sequence Current After Equivalence | Bias   |
|------------|---------------|---------------------------------------------|---------------------------------------------|--------|
| Wenshang   | 525.00        | 26.7412∠274.2° | 26.4708∠273.21° | 0.0101 |

Figure 4 Equivalence structure of 500kV grid nodes
The power angle of Jiaxiang Power Plant before equivalence

The power angle of Yunhe Power Plant

Figure 5 Three-phase short circuit fault waveform of Wenshang 500kV bus

Through the the dynamic response curve after transformation is analyzed in Table 1. We can see the important characteristics of the dynamic response of 500 kV bus position in Figure 5 prototype system are very similar to those before and after equivalence, and the equivalence has better accuracy.

4. Impact simulation research on Shandong Power Grid YINDONG HVDC system

Shandong electric power is the main network form equivalent to 500kV in PSCAD. Fault simulation of 500kV transmission line in Shandong Power Grid [15,16]. Firstly, the AC line with distance close to Yindong HVDC transmission system is used for simulation. We take Jiaodong daze AC line as an example. Single phase ground fault and three-phase short circuit fault are set in Jiaodong side of AC line. The fault starts from 0.4s and is eliminated after 0.05s. Figures 6 and 7 describe the simulation configuration.

Fig. 6: Yindong DC system waveform in Single-phase ground fault of Jiaodong Daze AC power line
Figure 6 and Figure 7 can describe the single-phase ground fault and three-phase short circuit fault of AC line close to Yindong HVDC transmission system, which we believe that this will have a great impact on Yindong HVDC transmission network. If the fault comes, the DC voltage suddenly decreases, the current increases, the arc extinguishing angle decreases, and the active power decreases, which indicates that the commutation failure of the system. Then we use the AC line away from Yindong HVDC transmission system for simulation. Take Guangshou AC line as an example. Single phase ground fault and three-phase short circuit fault are set in Guangzhou side of AC line. The fault occurred in 0.4s and ended after 0.05s. The simulation results are shown in Figure 8 and Figure 9.
It can be seen from figure 8 and Figure 9 that the three-phase short circuit fault of AC line far away from Yindong HVDC transmission system has a great impact on Yindong HVDC transmission system. When the fault comes, the DC line voltage will decrease, the current value will increase, the arc extinction angle will decrease, the active power will decrease, and the commutation will fail. However, the influence of single-phase ground fault on HVDC transmission system is very small, the change of voltage, current and arc extinguishing angle is not big, which does not lead to commutation failure.

5. Conclusion
In this paper, through research and analysis, Shandong power grid has symmetric and asymmetric faults. What we can know is that as the electrical distance between AC line and DC transmission system increases, the impact on Yindong DC transmission system is relatively small. If it is the same AC line, in the same situation, the impact of single-phase ground fault on DC system is far less than that of three-phase short circuit fault. In order to reduce the frequency of commutation failure of DC system, we must monitor the AC line which is short from HVDC system to prevent single-phase ground fault and three-phase short circuit fault. In order to avoid the occurrence of three-phase short circuit fault, AC lines with long electrical distance from HVDC transmission system should be used. On this basis, this paper improves Shandong power grid, proposes a 220kV power grid model, and carries out fault simulation for 220kV power grid, which provides guidance and theoretical basis for fault analysis and prediction in the research. It provides a provides a very useful theoretical analysis and reference for the operation and maintenance of ±660kV DC transmission project of Yindong line

Author
Zhao Xiaoxiao, born in Zhejiang, China in 1981, obtained a master's degree in electrical engineering from Xihua University in Chengdu, China in 2006. Currently, she is an associate professor of State Grid at Shandong Jinan State Grid Institute of Technology. Her current research is on-line monitoring and fault diagnosis of high voltage equipment.

Yun Yuxin, born in Zibo, Shandong in 1979, male, doctorate, engineer, research direction: online monitoring and fault diagnosis technology for electrical equipment, etc.

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