Simulation model of Ximeng-Taizhou 800 kV UHVDC transmission system based on PSCAD

Jian Liu, Ziyun Sun, Cui Tang*

School of Electrical and Information Engineering Wuhan Institute of Technology, Wuhan, China

*Corresponding author e-mail: 11100401@wit.edu.cn

Abstract. In order to study the changing characteristics of electrical variables during the operation process of UHVDC system with hierarchical connection to AC system, using the main circuit parameters of Ximeng-Taizhou 800 kV UHVDC transmission system which has been put into operation and referring to the control system of CIGRE HVDC standard test system, the simulation models of the AC system, converter, converter transformer, flat wave reactor, AC and DC filter and DC line of the transmission system of the Ximeng-Taizhou project are established by PSCAD. The model is used to simulate the positive, negative and bipolar full voltage operation mode, and the simulation results are compared with the system design parameters. It can be seen that the simulation model can more accurately simulate the Ximeng-Taizhou project, and can be used as an effective simulation tool for further research on the UHVDC transmission projects such as the Ximeng-Taizhou project with hierarchical connection to AC system.

Keywords: UHVDC transmission system, simulation model, PSCAD/EMTDC, Ximeng-Taizhou project, 800kV.

1. Introduction

Ximeng-Taizhou ±800kV UHVDC transmission project is an important part of China's action plan on air pollution prevention and the State Grid's "four AC and four DC" UHVDC project [1]. The construction of Ximeng Taizhou project can accelerate the transformation of resource advantages in Inner Mongolia, solve the problem of power shortage in Jiangsu Province, improve the quality of atmospheric environment, and improve the national AC and DC power grid. All of them are of great significance. In order to do more research on the Xitai project, it is urgent to build a simulation model to simulate the project.

At present, the simulation modeling of UHVDC transmission system mainly focuses on Yunguang project [2], Tianguang project [3], Zhangbei project [4] and other HVDC transmission projects. Xitai project is the first UHVDC transmission project with rated capacity up to 10000MW in the world. The biggest difference between Xitai project and conventional ±800kV UHVDC transmission project is that Ximeng Taizhou ±800kV UHVDC transmission project is the first transmission project with receiving end connected to 500kV / 1000kV AC power grid in the world.
The CIGRE HVDC model in PSCAD [5] adopts single-stage 12 pulse converter and is aimed at the simulation model of 500kV HVDC transmission system, while the 800kV UHVDC transmission system in Xitai adopts the main connection mode of single pole double 12 pulse converter in series, and the inverter station is connected to the AC grid layer by layer. It can be seen that the CIGRE HVDC standard test system model is difficult to meet the requirements of simulating the operation of Xitai project. The establishment of a simulation model that can simulate the Xitai project is of great significance for the study of UHVDC transmission project with layered access to AC system at the receiving end.

At present, in recent years, a lot of research has been done on Modeling of UHVDC transmission system at home and abroad, and the research on hierarchical access of UHVDC transmission system to AC system is also increasing. In recent years, a lot of research has been done on Modeling of UHVDC transmission system at home and abroad, and the research on hierarchical access of UHVDC transmission system to AC system is also increasing. Literature [6-7] studies the optimization method to improve the hierarchical access to UHVDC transmission system, and literature [8-10] studies the control system optimization of UHVDC transmission system with hierarchical access to AC system. However, literature [6-10] has not carried out the simulation modeling of the primary side electrical components and the secondary side of this system.

Aiming at the above problems, this paper uses PSCAD / EMTDC simulation program to establish the primary side and secondary side simulation models of transmission system according to the main wiring parameters of Xitai project[11]. The simulation results show that the waveform data obtained are consistent with the original design parameters of the system, which verifies the credibility of the simulation model.

2. Model parameters of Ximeng-Taizhou UHVDC transmission system

2.1. Main operation parameters of AC system

The parameters of AC system at rectifier side and inverter side of Ximeng Taizhou UHVDC transmission system are as follows: the rated operating voltage of AC system at Ximeng converter station in Inner Mongolia side is 530kV, the highest steady state voltage is 550kV, the lowest steady state voltage is 500kV, the lowest extreme voltage is 475kV, and the highest extreme voltage is 550kV; The rated operating voltage of Taizhou converter station system connected to 500 kV AC voltage side in Jiangsu side is 520 kV, the highest steady state voltage is 525 kV, the lowest steady state voltage is 500 kV, the lowest extreme voltage is 475 kV, and the highest extreme voltage is 550 kV; Taizhou converter station system in Jiangsu side is connected to 1000kV AC voltage side, with rated operating voltage of 1050kV, maximum steady-state voltage of 1070kV, minimum steady-state voltage of 1000kV, minimum extreme voltage of 950kV and maximum extreme voltage of 1100kV.

2.2. Converter

The simulation model of Xitai project adopts the connection mode of double 12 pulsating converters in series. Two converter bridge models in PSCAD are connected in series to form a 12 pulsating converter. This connection mode requires four converter bridge models in series. Two 12 pulse converters distribute the voltage according to ± (400 +400) kV.

2.3. Converter transformer

Single phase double winding converter transformer is used in HVDC transmission projects with capacity of 3000MW and above in China. Single phase double winding transformers with Y0 / Y and Y0 / △ connection modes are also used in Ximeng station and Taizhou station. The capacity of single transformer in Ximeng station is 509.3MVA, the commutation impedance is 0.21, the rated phase voltage of grid side winding is 306 kV, the rated voltage of Y0 / Y connection type valve side winding is 99.8kV, and the rated voltage of Y0 / △ connection type valve side winding is 172.8kV. The simulation model established in this paper selects a single 1536MVA three-phase double winding transformer, and the wiring type, commutation impedance and rated voltage of winding are consistent.
with the actual value. The capacity of a single transformer in Taizhou station is 488.7MVA, the rated phase voltage of grid side winding is 300.2kV and 606.2kV respectively, and the commutation impedance is 0.20. The simulation model selects a three-phase two winding transformer with a single capacity of 1536MVA, and the wiring type, commutation impedance and winding rated voltage are consistent with the actual value.

2.4. Flat wave reactor
Both Ximeng converter station and Taizhou converter station use dry type air core flat wave reactor. The flat wave reactor adopts the symmetrical arrangement of pole line and neutral line, and the inductance of each stage is 300mH, that is, $3 \times 50\text{mH}$ is configured on each pole line and neutral line side.

2.5. AC and DC filter
The simulation model of this paper is established by referring to the filter design models of Yunnan-Guangzhou Project and Zhaqing project, and the equipment capacity suitable for this project is determined by calculation and analysis. The selected AC and DC filters are shown in Figure 1 and Figure 2 respectively, and the filter parameters are shown in Table 1.

| Filter model | $C_1/\mu F$ | $L_1/mH$ | $R/\Omega$ | $C_2/\mu F$ | $L_2/mH$ | $C_3/\mu F$ | $L_3/mH$ |
|--------------|-------------|-----------|-------------|-------------|-----------|-------------|-----------|
| DT11/24      | 2.15        | 12.85     | 500         | 5.64        | 9.51      | —           | —         |
| DT13/36      | 2.15        | 6.24      | 500         | 3.87        | 9.51      | —           | —         |
| HP3          | 2.16        | 685.91    | 1800        | 14.77       | —         | —           | —         |
| SC           | 2.16        | 2.04      | —           | —           | —         | —           | —         |
| DC filter    | 1.2         | 7.3       | —           | 3.18        | 15.4      | 16.5        | 0.4       |

**Table 1.** Parameters of AC and DC filters

![Figure 1. DC filter](image1)

![Figure 2. AC filter](image2)
2.6. DC transmission line

The total length of Xitai UHVDC transmission line is 1620km, and the earth resistivity along the line adopts the default value of 1000 Ω・m. The relative geomagnetic coefficient is 1.0.

3. Modeling of ±800kV UHVDC transmission system from Ximeng to Taizhou

The simulation model of Xitai project has voltage level of ±800 kV, DC rated current of 6250 A and rated power of 10000 MW. The rated voltage of AC system on rectifier side is 500kV, and the rated voltage of AC bus is 525kV; The high-end valve group is connected to 1000 kV AC power grid, and the low-end valve group is connected to 500 kV AC power grid. Both Ximeng station and Taizhou station use single-phase double winding transformer, and the connection modes are Y0 / Y and Y0 / △ respectively. The capacity of single transformer in Ximeng station is 509.3MVA, the commutation impedance is 0.21, the rated line voltage of valve side winding is 172.8kV, and the rated current of valve side y winding and △ winding is 5103A. The simulation model selects a three-phase two winding transformer with a single capacity of 1536MVA, and the wiring type, commutation impedance and winding rated voltage are consistent with the actual data. The capacity of single transformer at inverter side is 488.7MVA, the rated line voltage of valve side winding is 165.8kV, and the rated current of Y winding and △ winding at valve side is 2946a. The simulation model also selects a single 1536MVA three-phase double winding transformer, and the wiring type, commutation impedance and winding rated voltage are consistent with the actual data.

In order to meet the needs of the model transmission system control, this paper changes the CIGRE standard model control system in PSCAD simulation platform. The rectifier side adopts the constant current control, and the current command is the minimum value of the voltage dependent current order limiter (VDCOL) compared with 1pu value. The steady-state current is 6.25kA. After PI, the current reference value and measured value output a value-β. Then the trigger angle can be obtained by subtracting β from π. The inverter side is connected to AC power grid by layers. The high-end valve group is connected to 1000kV AC power grid, and the low-end valve group is connected to 500kV AC power grid. The inverter side adopts the constant extinction angle (CEA) control of 17°, that is, the control voltage is 800kV (excluding the DC line voltage drop). The minimum constant extinction angle and standard value of the four converters are output through PI link, and the output beta minus π is used as the trigger angle value. The established control system is shown in Figure 3[12-14], the arc extinction angle and trigger angle waveform of the control system are shown in Figures 4 and 5, and the established simulation model is shown in Figure 6.

Figure 3. Structure diagram of control system
4. Model simulation verification

The simulation model of Xitai project is built by PSCAD / EMTDC simulation platform. There are many operation modes for the simulation model, including:

1) Bipolar total pressure operation mode, in which each pole of each converter station has double 12 pulsating converters in series operation;

2) In bipolar half pressure operation mode, there is only one 12 pulse converter in each stage of each converter station;

3) In the operation mode of monopole total pressure earth return line, one pole is shut down, and the other pole has two 12 pulsating converters running in series and returning from earth;

4) In the monopole and half pressure earth return line operation mode, one pole is out of service, and the other pole has only one 12 pulsating converter running and returning from the earth;

5) The single-stage full pressure metal return operation mode, the first stage shutdown, the other pole double 12 pulsating converter in series operation, return from the metal circuit;

6) In the single-stage half pressure metal return operation mode, one pole is out of service, and the other pole has only one 12 pulsating converter, which is returned by the metal circuit;

7) In the bipolar mixed voltage operation mode, two 12 pulse converters are in series operation on one pole and only one 12 pulse converter is in operation on the other pole.
According to the research content of this paper, the simulation model will be compared and analyzed with the actual results of the project under the conditions of positive full voltage operation, negative full voltage operation and bipolar full voltage operation. Simulation of positive full voltage operation mode.

4.1. Simulation of positive full voltage operation mode

The voltage and current waveforms of the simulation model in this mode are shown in Figure 7 and Figure 8 respectively.

According to the design parameters of main circuit of Xitai project, the rated voltage, current and power of the project should be 800kV, 6.25kA and 10000 MW respectively. According to the waveforms in Fig. 7 and Fig. 8, the simulation voltage is about 800 kV and the current is close to 6.25 kA. The simulation results of this paper are basically consistent with the positive operation of Xitai project.

4.2. Simulation of negative full voltage operation mode

The voltage and current waveforms of the simulation model in this mode are shown in Figure 9 and Figure 10 respectively.

According to the design parameters of main circuit Xitai project, the rated voltage, current and power of the project under this operation mode should be -800kV, -6.25kA and 10000 MW respectively. According to the waveforms in Fig. 9 and Fig. 10, the simulation voltage is about -800 kV and the current is close to -6.25 kA. The simulation results of this paper are basically consistent with the negative electrode operation of Xitai project.
4.3. Simulation of bipolar total voltage operation mode

The voltage and current waveforms of the simulation model in this mode are shown in Figure 11 and Figure 12 respectively.

Figure 9. DC current waveform in full voltage operation of negative electrode

Figure 10. DC voltage waveform in full voltage operation of negative electrode

Figure 11. DC current waveform of bipolar full voltage operation

Figure 12. DC voltage waveform of bipolar full voltage operation
According to the design parameters of main circuit of Xitai project, the rated voltage of positive pole is 800kV, the rated current is 6.25kA, the rated voltage of negative pole is 800kV, the rated current is 6.25kA, and the total rated power is 10000mw. According to the waveforms in Fig. 11 and Fig. 12, the simulation voltage of the positive electrode is close to 800 kV, and the simulation current is about 6.25 kA; The simulation voltage of negative electrode is about 800 kV and the simulation current is close to 6.25 kA. The simulation results of this paper are basically consistent[15] with the bipolar operation of Xitai project.

5. conclusion

This paper takes Ximeng-Taizhou HVDC transmission project as the research object, establishes the system simulation model in PSCAD / EMTDC simulation platform according to the main circuit parameters of Ximeng-Taizhou HVDC transmission project, and the positive, negative and bipolar full voltage operation of the model are simulated and analyzed. The simulation results show that when the simulation model is running at full positive voltage, the voltage is +800 kV and the current is about +6250 A; When the negative electrode operates at full voltage, the voltage is -800 kV and the current is about -6250 A; The voltage is ±800kV and the current is about ±6250 A under bipolar full voltage operation. Therefore, the simulation model of Ximeng-Taizhou ±800kV UHVDC transmission system established in this paper can be used as an effective tool for further study of Ximeng-Taizhou project, and also as an effective tool for studying the hierarchical access of 800kV UHVDC transmission system to AC system.

Acknowledgments

We thank the other authors for their help and helpful inspiration and guidance. We are very grateful for the help of external funds.

1. The Middle-aged and Young Talents Science Research Foundation of Hubei Provincial Department of Education 2019: Fault Characteristic Analysis and Protection Research of Non Whole Lines on the Same Tower (Q20191505).

2. Scientific Research Foundation of Wuhan Institute of Technology 2019: Research on Relay Protection and Countermeasures of Double Circuit Series Compensation Transmission Line on the Same Tower (K201906).

References

[1] Y. Zhou, D. Zhuojiang and Y. Fenwang, "The Development of HVDC Transmission System," in 2012 Third International Conference on Digital Manufacturing & Automation, Guilin, China, China, 2012 pp. 907-910.

[2] Q. Guo, C. Luo, X. Lin, L. Deng, S. Li and M. Liao, "Analysis of Harmonic Instability Induced by Lightning Strike in a LCC-HVDC System," 2020 4th International Conference on HVDC (HVDC), 2020, pp. 321-325.

[3] P. Liu, R. Che, Y. Xu and H. Zhang, "Detailed modeling and simulation of +500kV HVDC transmission system using PSCAD/EMTDC," 2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2015, pp. 1-3.

[4] M. Guo, X. Li, Z. Gao and G. Su, "Simulation and Analysis on Stability Improvement of Zhangbei Renewable Energy Transmission via VSC-HVDC Based on RTDS," 2020 4th International Conference on HVDC (HVDC), 2020, pp. 299-303.

[5] X. Liancheng and K. Zhiliang, "Study on fault simulation of HVDC system based on PSCAD/EMTDC," 2017 International Conference on Advanced Mechatronic Systems (ICAMechS), 2017, pp. 441-445.

[6] Q. Wang, J. Zhang, J. Yi and H. Luo, "An optimization method to improve the transmission capability of AC/DC system with hierarchical access UHVDC," 2017 IEEE Conference on Energy Internet and Energy System Integration (EI2), 2017, pp. 1-4.

[7] W. Jiang, J. Ruan, D. Song, L. Xie, J. Tang and W. Sun, "Optimization of DC Terminal Location
for UHVDC Hierarchical Connection to Power Grid," 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2), 2018, pp. 1-5.

[8] W. Sun et al., "Analysis on the operating characteristic of UHVDC hierarchical connection mode to AC system," 2015 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2015, pp. 1834-1837.

[9] Y. Tan, W. Yao, Z. Shu, X. Cai, C. Li and J. Wen, "Coordination Control of Commutation Failure Preventions for UHVDC Hierarchical Connection to AC Grid," 2018 International Conference on Power System Technology (POWERCON), 2018, pp. 2069-2165.

[10] X. Li, Y. Pu, Y. Ma, L. Xiong and Q. Guo, "DC voltage balance control of UHVDC system with hierarchical connection mode," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, 2017, pp. 3003-3008.

[11] LI Bo, SU Yijing, ZHAO Bin, et al. Study and design of main circuit parameters for 800 kV/10000 MW DC power transmission project from Ximeng to Taizhou [J]. Energy Engineering, 2017 (03): 27-33.

[12] N. Zhang, F. Gan, Z. Fu, Y. Li and Q. Zheng, "Simulation of HVDC Transmission Control System on MODELS," 2018 10th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC), 2018, pp. 179-182.

[13] R. Li, L. Yu, L. Xu and G. P. Adam, "Coordinated Control of Parallel DR-HVDC and MMC-HVDC Systems for Offshore Wind Energy Transmission," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 8, no. 3, pp. 2572-2582, Sept. 2020.

[14] A. Bidadfar et al., "Power System Stability Analysis Using Feedback Control System Modeling Including HVDC Transmission Links," in IEEE Transactions on Power Systems, vol. 31, no. 1, pp. 116-124, Jan. 2016.

[15] Haipeng Xie, Zhaohong Bie, Pengfei Dong and Chao Zheng, "The influence of commutation failures on the reliability of HVDC transmission systems," TENCON 2015 - 2015 IEEE Region 10 Conference, 2015, pp. 1-4.