Influence of HVDC Transmission on DC Bias of AC Grid and Its Treatment

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Abstract. With the rapid development of China's electric power industry, the high-voltage and long-distance direct current (DC) transmission effectively solved the problem of uneven power distribution. When the high voltage direct current transmission is in unipolar operation or bipolar asymmetric operation, part of the DC current will flow into the transformer winding through the grounded neutral point, which will cause the DC bias problem. This article used CDEGS software for modeling, and introduced the process of CDEGS software for DC bias simulation modeling. In this paper, the DC bias model of regional power grid is first established, based on the Zhejiang power grid topology and the test soil resistivity date. Then the DC bias currents of the transformers are calculated, and finally the corresponding treatment measures are proposed. According to the governance measures, this article adjusted the simulation model. The calculation results show that the treatment measures have good effects, which can provide an important reference for the future treatment of transformer DC bias.

Keywords. Electric power, transformer DC bias, DC bias model

1. Introduction

High voltage direct current (HVDC) transmission has developed rapidly in many countries due to its advantages of large transmission capacity, long transmission distance and low line loss [1-3]. However, when the HVDC is under maintenance or failure, it will implement unipolar operation or bipolar asymmetric operation. The DC current will flow back through the earth and flow into the transformers by the grounded neutral point, causing the transformers DC bias effect [4-8]. The DC biasing effect of the transformers will cause abnormal vibration, increase of harmonics, and malfunction of relay protection. In order to solve the problems, domestic and foreign scholars have carried out a lot of research, mainly focusing on two aspects: (1) the distribution of DC current in the AC power grid; (2) the harm of DC bias to power equipments and its treatment measures. This paper focuses on the DC bias problem of Baihetan-Zhejiang DC under construction. We collected the topological structure of Zhejiang Power Grid, tested the soil resistivity around the grounding pole, established the DC bias calculation model of Zhejiang Power Grid, and calculated the DC bias distribution current of the regional power grid, and finally proposed targeted treatment measures.

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2. DC Bias Calculation Model

2.1. Grid Topology Model

The ground electrode of ±800kV Baihetan-Zhejiang HVDC is located in Chen'an Village, Huzhou city. Due to the higher unit density and complex structure of Zhejiang Power Grid, it will have a major impact on the DC bias of Zhejiang Power Grid. Similarly, the Jinsu HVDC ground electrode around Huzhou City will also affect the substations in Zhejiang area. Therefore, it is necessary to comprehensively consider the DC bias effect of the two HVDC transmissions in the model [9, 10].

According to the classic grounding theory, when a large current is injected into the ground along with the grounding electrode, a spatial electric field will be formed in the ground, and the ground potential of the surrounding area will change. When the neutral point of the substation is grounded, the DC current will flow into the transformer by the neutral point and flows to the remote substations through the overhead lines connected to each other. Therefore, to calculate the distribution of DC current in transformers, two models of electric field and circuit must be considered at the same time.

There are multiple connection types for transformer, bus and overhead lines of the substation. According to different connection types, this paper equates the transformer to six basic forms, as shown in figure 1. Where R_g is the transformer grounding resistance, R_c is the DC resistance of the autotransformer common winding, R_s is the autotransformer series winding DC resistance, R_M is the non-autotransformer medium voltage side winding resistance, R_H is the non-autotransformer high voltage side winding, the subscript number is the main transformer numbering.

(a) Parallel operation of autotransformers

(b) High-voltage parallel and medium-voltage separate operation of autotransformer

(c) Separate operation of autotransformer

(d) Parallel operation of non-autotransformers

(e) High-voltage parallel and medium-voltage separate of non-autotransformer

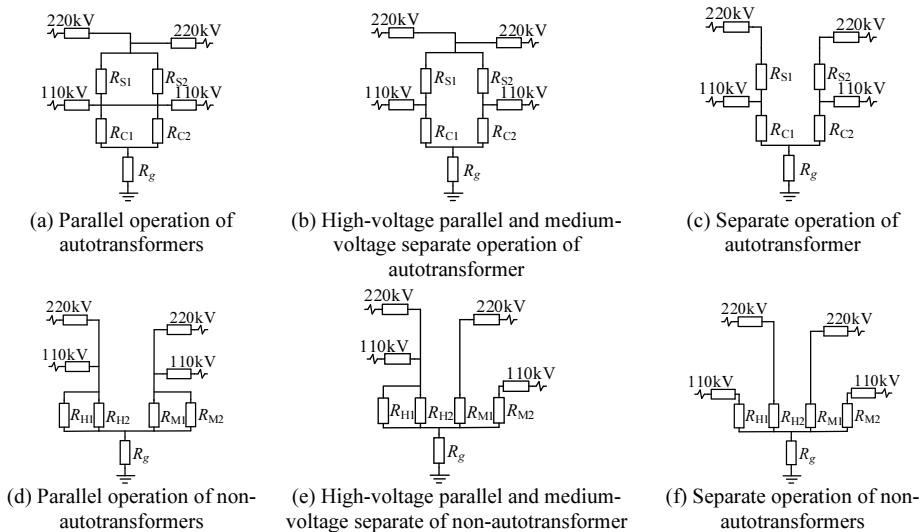(f) Separate operation of non-autotransformers

Figure 1. Equivalent resistance network of different transformer connection methods.

In order to fully consider the interaction between the substations and the transmission lines, this paper takes the AC grid around the DC ground electrode as the research object, and establishes the DC bias simulation model of Zhejiang Power Grid.

In the model, total number of substations is 1252, including 5 substations of 1000kV, 54 substations of 500kV, 238 substations of 220kV, and 955 substations of 110kV. The total number of transmission lines is 1288, including 9 lines of 1000kV, 53 lines of 500kV, and 347 lines of 220kV, 879 lines of 110kV, the model as shown in figure 2. The straight line represents the transmission line, and the dot represents the substation.
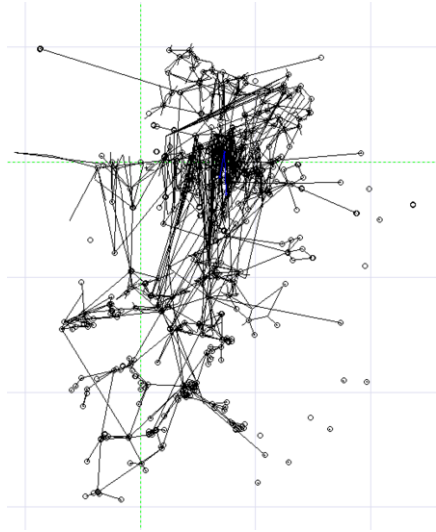

Figure 2. Simulation model of DC Bias in Zhejiang power grid.

2.2. Soil Resistivity

The soil model is a key parameter in the DC bias calculation. In order to obtain accurate soil parameters. The deep soil resistivity of 10 substations was detected, including Ji'an, Anshan Square, Jindingzi, Wandan Village, Huangzhi, Baique, Nanxun, Taijia, Yingxi and Heiqiaozi. The distribution of substations is shown in figure 3. The four-pole method and magnetotelluric sounding method are used to detect the soil resistivity near the DC ground electrode, and the detection depth is 10 km.
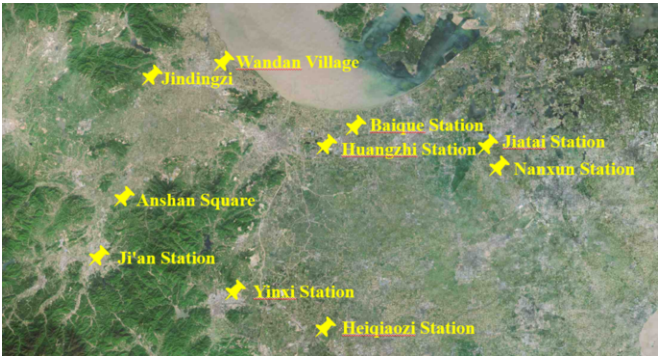

Figure 3. The distribution of substations.

Combining the single-point electrical sounding results of 10 substations, the resistivity contour maps of different depths are formed. When setting up the soil

parameter model, the horizontal layered model is generally used, so this paper simplified the soil electrical conductivity characteristics into different horizontal layered structures. According to the detection results of the above soil resistivity, this paper divides the soil in the calculation area into 7 layers, as shown in table 1.

Table 1. Soil resistivity distribution.

	Depth (m)	Thickness (m)	Resistivity ($\Omega \cdot m$)
Layer 1	0~100	100	6.5
Layer 2	100~500	400	120
Layer 3	500~2000	1500	455
Layer 4	2000~5000	3000	2145
Layer 5	5000~8000	3000	5500
Layer 6	8000~10000	2000	5100
Layer 7	>10000	infinite	8500

Combining the power grid model and the soil model, the DC bias model of Zhejiang Power Grid can be obtained.

3. DC Bias Calculation Results

According to the experience of bias control, the DC bias current limits of 500kV, 220kV, and 110kV substations are 20A, 15A, and 10A respectively [11, 12]. When Baihetan-Zhejiang HVDC unipolar operating current is 5000A, the substations with current exceeding the limit near the ground electrode are shown in table 2, based on the simulation model of Zhejiang grid. There are 6 substations with bias current exceeding the limit. The maximum DC bias current is 220kV Ji'an station, up to 105A. The main reason is that it is very close to the ground electrode, only 15km. Other substations are mainly distributed in the nearby Huzhou and Hangzhou areas.

Table 2. Baihetan ground electrode current overrun substation.

Voltage level	Substation	Transformer type	High voltage side (series winding) (A)	Medium voltage side (common winding) (A)	Distance to DC ground electrode (km)
220kV	Changshuo	Non-autotransformer	37.10	-32.70	26
220kV	Ji'an	Autotransformer	73.10	105.00	14
220kV	Kunlun	Autotransformer	-3.79	-20.40	66
220kV	Shengshan	Autotransformer	1.09	-17.30	74
220kV	Yangzi	Non-autotransformer	17.60	18.30	39
110kV	Wangjia	Non-autotransformer	28.6	0	40

Since the Jinsu ground electrode is located in Jiangsu Province near Huzhou, this HVDC will also cause DC bias effects on substations in Huzhou. Therefore, it is necessary to calculate the DC current of the substation winding of the Huzhou Power Grid when the Jinsu HVDC is unipolar operating. There are 20 substations in Huzhou whose current exceeds the limit. Among them, the substations that overlap with Baihetan-Zhejiang DC are shown in table 3.

According to the above calculation results, the Baihetan-Zhejiang HVDC has a greater impact on the Huzhou and Hangzhou substations near the ground electrode, it is necessary to provide treatment suggestions for the substations in the above-mentioned areas. At present, there are two main treatment methods: one is resistance limiting, and the other is capacitance blocking. The resistance limiting method is to connect a resistor in series at the neutral point of the transformer to limit the DC current within the range. The capacitor DC blocking method is to connect a capacitor in series with the neutral point of the transformer to completely block the DC path.

Table 3. Jinsu ground electrode current overrun substation.

Voltage level	Substation	Transformer type	High voltage side (series winding) (A)	Medium voltage side (common winding) (A)	Distance to DC ground electrode (km)
220kV	Changshuo	Non-autotransformer	-15.70	-2.98	74
220kV	Ji'an	Autotransformer	-17.50	-14.40	83
220kV	Kunlun	Autotransformer	-3.67	-28.80	63
220kV	Shengshan	Autotransformer	-20.00	36.20	29
220kV	Yangzi	Non-autotransformer	-19.50	-14.20	76

Firstly, according to the calculation results of Jinsu HVDC, the substations that need to be treated and observed in the Huzhou area are divided into three priority levels according to risk:

(1) There is only 1 substation whose winding current is positive and exceeds the limit, which is the priority treatment substation.

(2) After the priority substation is treated, the transfer of the DC bias current will cause the current of the adjacent substation to increase, and these two stations with positive currents need to be further treated. Considering the dispersion of the calculated parameters, it is recommended to treat after testing.

(3) Substations with negative currents are not the source of the bias current entering the AC grid, so there is no need for direct control. However, it is necessary to test the substations whose current exceeds the limit before the treatment of (2).

After taking the above-mentioned treatment measures for Jinsu HVDC, the bias current of all substations is controlled within the limit. Among them, Shengshan is the priority substation for governance, and Kunlun are the observation substations.

After Jinsu HVDC treatment, supplementary treatment of Baihetan-Zhejiang HVDC is required. The treatment plan of each substation is shown in table 4.

Table 4. Treatment plan.

Voltage level	Substation	Transformer type	Winding	Equipment	Priority levels
220kV	Shengshan	Autotransformer	Common winding	Resistance	Priority treatment
220kV	Kunlun	Autotransformer	/	/	Observation
220kV	Changshuo	Non-autotransformer	High voltage winding and Medium voltage winding	Resistance	Supplementary treatment
220kV	Ji'an	Autotransformer	Common winding	Resistance	Supplementary treatment
220kV	Yangzi	Non-autotransformer	High voltage winding and Medium voltage winding	Resistance	Supplementary treatment

After adopting the above treatment measures, when the Baihetan-Zhejiang HVDC is in unipolar operation, the bias current distribution of the over-limit substation of the

Huzhou power grid is shown in table 5. After treatment, the bias currents of all substations are within the limit, which reflects the effectiveness of the treatment plan.

Table 5. Calculation result of bias current after treatment.

Voltage level	Substation	Transformer type	High voltage side (series winding) (A)	Medium voltage side (common winding) (A)	Distance to DC ground electrode (km)
220kV	Changshuo	Non-autotransformer	4.26	2.77	74
220kV	Ji'an	autotransformer	10.70	7.11	83
220kV	Kunlun	autotransformer	-2.12	-13.40	63
220kV	Shengshan	autotransformer	0.60	-0.32	29
220kV	Yangzi	non-autotransformer	1.57	1.49	76
1100kV	Wangjia	non-autotransformer	5.3	0	40

4. Conclusion

Based on the field-circuit coupling method, this paper establishes a DC bias model for Zhejiang Power Grid, and proposes treatment measures for substations with current overruns in the area. The specific conclusions are as follows:

(1) The up-ground model of the power grid in Zhejiang is established, mainly including substations locations, transformers and connection types, bus, overhead lines and neutral grounding type.

(2) The underground model is mainly the soil model. The resistivity of the soil is calculated by the quadrupole method and the magnetotelluric sounding method, then the earth soil layering model with different resistivity is established.

(3) The bias current caused by the unipolar operation of Baihetan-Zhejiang Jinsu HVDCs is analysed, and effective treatment measures are proposed based on the calculation results. The treatment results show that the proposed plan can effectively restrain the bias current in Zhejiang Power Grid and has engineering practical value.

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