Research on Influence of Converter Transformer Grouping and Receiving End Power Grid Structure on Converter Transformer DC bias

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Abstract. When ±800kV UHVDC project was put into operation, DC bias problem can not be ignored. In this paper, a calculation model for DC bias current is established based on Xiluodu-Zhexi UHVDC project data. Converter transformer grouping and receiving end power grid structure are considered. The converter transformer DC bias current is calculated by node voltage method. The influence of different converter transformer grouping modes, distance between grounding electrode and substation, and the feeder length and the number of feeder loop are analysed. The results show that, single-phase converter transformer bias current is maximum with full load and 6 converter transformers under 1/2 monopole earth mode. And bias current level of converter can be reduced in planning and designing.

1. Introduction
During the operation and debugging of Chinese Xiluodu-Zhexi ±800kV HVDC transmission project, DC bias problem is noticed. When operating in monopole earth mode and bipolar unbalanced mode, the DC bias current of neutral point in AC power grid and converter transformer is larger. The ±800kV UHVDC transmission project capacity of is from 5000MW to 8000MW. Considering the factors such as the manufacturing capacity of the converter transformer, the dual 12 pulse series connection mode is adopted for the two poles of the 800kV converter station [1]. Under different operation mode, grounding current and converter transformer groups change, the DC bias also changes. When the substation ground potential is constant, AC bus feeder circuit number and length change, the DC resistance of the bias current of the transmission path changes [2]. When the feeder circuit number and length is constant, feeder connected AC substation and grounding distance have an impact on the AC substation earth potential [3-4].

This paper provides an equivalent model of bias current flow path to analyse the influence of converter transformer grouping. Then analysis model of influence of distance on the bias current is established to influence of distance between grounding electrode and substation. Ultimately, the influence of the feeder length and the number of feeder loop is considered.
2. Influence of converter transformer grouping

Because of the different converter transformer grouping modes of the ±800kV converter station, the grounding current is different, and the degree of DC bias is different [5]. As table 1 shows, all possible operation modes of ±800 kV converter station are given. The number of converter transformers put into operation, transmission capacity and grounding current under various operation modes are listed.

Table 1. Converter transformer grouping operation mode.

| Operation mode          | Number of converter transformer | Transmission capacity/ $S_t$ | The grounding current/ $I_t$ |
|-------------------------|---------------------------------|-------------------------------|-------------------------------|
| Complete bipolar        | 24                              | 100%                          | 1% $I_{amb}$                 |
| 3/4 Bipolar             | 18                              | 75%                           | 1% $I_{amb}$                 |
| 1/2 Bipolar             | 12                              | 50%                           | 1% $I_{amb}$                 |
| Complete monopole earth| 12                              | 50%                           | 100%                         |
| Complete monopole metal loop | 12                | 50%                           | 0                             |
| 1/2 Monopole earth      | 6                               | 25%                           | 100%                         |
| 1/2 Monopole metal loop | 6                               | 25%                           | 0                             |
| Bipolar unbalance       | 12(18,24)                       | 25%~100%                      | 1%~99%                       |

There are 8 converter transformer grouping operation modes. The complete monopole earth, 1/2 monopole earth and bipolar unbalance operation have larger grounding current, and the grounding current under bipolar unbalanced mode is less than $I_t$. According to the number of transformers under the three operation modes, the equivalent model of the three-phase flow path between the converter station and the AC substation connected by the feeder can be established, as shown in Figure 1. In Figure 1, $E_0$, $E_1$, $E_2$...$E_n$ are earth surface potential of converter stations and substations at rated grounding current, respectively, $R_{gb}$, $R_{g1}$, $R_{g2}$...$R_{gn}$ are grounding resistance of converter stations and substations, respectively. $R_s$, $R_{t1}$, $R_{t2}$...$R_{tn}$ are three phase parallel DC resistance of transformer windings in converter stations and substations, respectively. $R_{t1}$, $R_{t2}$... $R_{tn}$ are three phase DC resistance of the feed lines of the converter station.

The single-phase double-windings group transformer is used in the ±800kV converter transformer, and the single converter transformer DC resistance is defined as $R_{gb}$. $E_0$ and $E$ are defined as the potential value at the rated grounding current. According to the three grouping modes above, the grounding bias current and the bias current flowing through the single-phase converter transformer are calculated by the formula respectively. As table 2 shows, under bipolar unbalanced operation mode, the grounding current is less than $I_t$. Earth surface potential is less than that with rated grounding current. $\alpha$ is defined as the coefficient which is more than 0 and less than 1.

Table 2. Bias current under three modes which grounding current is not 0.

| Operation mode          | $R_s$          | Converter station grounding bias current | Single phase converter transformer bias current |
|-------------------------|----------------|-----------------------------------------|-----------------------------------------------|
| Complete monopole earth| $\frac{1}{12}R_m$ | $\frac{E-E_{0}}{R_{0}+R+\frac{1}{12}R_{0}}$ | $\frac{1}{12} \frac{E-E_{0}}{R_{0}+R+\frac{1}{12}R_{0}}$ |
| 1/2 Monopole earth      | $\frac{1}{6}R_0$ | $\frac{E-E_{0}}{R_{0}+R+\frac{1}{6}R_{0}}$ | $\frac{1}{6} \frac{E-E_{0}}{R_{0}+R+\frac{1}{6}R_{0}}$ |
| Bipolar unbalance       | $\leq \frac{1}{12}R_0$ | $\frac{\alpha(E-E_{0})}{R_{0}+R+R_{i}}$ | $\leq \frac{1}{12} \frac{\alpha(E-E_{0})}{R_{0}+R+R_{i}}$ |

The converter station grounding bias current and the single-phase converter transformer bias current are compared under three modes.

$$\frac{E-E_{0}}{R_{0}+R+\frac{1}{12}R_{0}} > \frac{E-E_{0}}{R_{0}+R+\frac{1}{6}R_{0}} > \frac{\alpha(E-E_{0})}{R_{0}+R+R_{i}}$$ (1)
The converter station grounding bias current and the single-phase converter transformer bias current are compared under three modes. It can be seen that the converter station grounding bias current is the maximum under complete monopole earth mode. The single-phase converter transformer bias current is the maximum under 1/2 monopole earth mode. So, the problem of DC bias under 1/2 monopole earth mode is the most serious.

3. Influence of distance between grounding electrode and substation

3.1. Parameter selection
The single-phase transformer of ZZDFPZ-321000/500 model is adopted for the ±800kV converter transformer. The windings DC resistance is 0.704Ω by the calculation of the nameplate parameters. The converter station grounding resistance is 0.1Ω. Single-phase autotransformer is adopted for 500kV AC transformer. The high voltage windings DC resistance and the medium voltage windings DC resistance are 0.238Ω and 0.097Ω, respectively. The grounding resistance is 0.2Ω. The 500kV AC line uses four split wires and the single-phase line resistance is 0.0187Ω/km.
When the influence of distance and other factors on the bias current of converter station is analyzed, the length of feeder, the number of loops and the distance between substation and grounding electrode have great influence on the bias current of converter station. It is advisable to select more parallel converter stations to reduce DC resistance in converter stations. Therefore, the operation mode of maximum bias current in converter station is adopted. That is the complete monopole earth operation mode.

3.2. Bias current model and calculation
Combined with Jinhua converter station and Jinsi grounding electrode, 4 substations to be connected to the converter station are proposed, which are numbered 1, 2, 3 and 4. Assuming that there are three cases of the distance between substations and grounding electrode shown in Table 3. Each substation autotransformer takes two groups of grounding. The feed line of the converter station is two back to each substation. The length of each feeder is 20km. The equivalent model of the bias current flow path can be set up as shown in Figure 1. $E_0$, $E_1$, $E_2$, $E_3$ and $E_4$ are the electric potential of the converter stations and four substations respectively [6].

**Table 3: Distance between substation and earth electrode (km)**

| Case  | Station 1 | Station 2 | Station 3 | Station 4 |
|-------|-----------|-----------|-----------|-----------|
| Case 1| 5         | 10        | 15        | 20        |
| Case 2| 10        | 20        | 30        | 40        |
| Case 3| 25        | 30        | 35        | 40        |

![Figure 1](image-url)
According to the six-layer soil structure data of the Jinsi grounding electrode, a horizontal homogeneous layered earth resistivity model is established [7-9]. Based on the ANSYS software, the earth current is set as 5000A. The boundary condition, the potential is 0, is added to the place away from grounding electrode 50km. The earth potential data of the Jinsi grounding electrode in 50km range is simulated, as shown in table 4. Among them, the distance between the Jinhua converter station and the grounding electrode is 23.5km, and the earth potential is 40.052V. Combined with the earth potential of each substation, the nodal voltage method is used to calculate the earth potential. The bias current of feeder branches and converter stations in three cases are shown in table 5.

**Tab.4 The earth potential data of Jinsi grounding electrode in 50km range**

| Distance (km) | Earth potential (V) |
|--------------|---------------------|
| 5            | 126.54V             |
| 10           | 87.947V             |
| 15           | 65.718V             |
| 20           | 50.003V             |
| 25           | 37.824V             |
| 30           | 27.875V             |
| 35           | 19.463V             |
| 40           | 12.176V             |

**Tab.5 Bias current of each feeder branch and converter station (A)**

| Case     | Branch1  | Branch2  | Branch3  | Branch4  | Converter station |
|----------|----------|----------|----------|----------|-------------------|
| Case 1   | 182.877  | 61.516   | -8.386   | -57.805  | 178.195           |
| Case 2   | 141.289  | 21.969   | -47.616  | -96.984  | 18.650            |
| Case 3   | 25.943   | -5.342   | -31.796  | -54.711  | -65.901           |

It can be seen from table 5 that: 1) The bias current flowing into the converter station of the substation nearest to the grounding electrode is the maximum. The bias current flowing out the converter station of the substation farthest to the grounding electrode is the maximum. 2) When the distance between substations and grounding electrode increases gradually, the sum of the bias current flowing into the converter station decreases gradually. When the distance increases further, the direction of bias current changes to outflow converter station.

4. The influence of the feeder length and the number of feeder loop

The ±800kV converter station is usually connected to three or four 500kV substations. and 500kV feeder loop is generally 8~10 loops. There are four 500kV substations, Shuanglong, Danxi, Wanxiang and Ningde, connected to Jinhua converter station by 10 lines. Shuanglong Station is connected by four loop lines, and the other stations are two loop lines [10-13].

With the earth potential remaining unchanged, Changing the length and the loop of feeder in the converter station. The DC resistance of the feeder branch changes accordingly, which affects the bias current. Because the influence of feeder length increasing (decreasing) and loop decreasing (increasing) on branch DC resistance are the same, only the influence of feeder loop on bias current is analyzed. The conclusion is also applicable to the analysis of the influence of feeder length.

Case 2 in table 3 is taken as the object, combined with the model shown in figure 1. The effect of the number of feeder loop on the bias current is studied in two cases. 1) The number of all the feeder loop in the converter station is changed to 1, 2, 3, 4. The change of the bias current is shown in table 6. 2) Only the number of one feeder branch is changed. The feeder branches of the substation 1 and substation 4 are changed from 1 to 4. The variation of the bias current is shown in table 7 and table 8.

**Tab.6 Effect of each feeder loop number variation on bias current (A)**

| Branch loop number | Branch 1 | Branch 2 | Branch 3 | Branch 4 | Converter station |
|--------------------|----------|----------|----------|----------|-------------------|
| 1                  | 118.713  | 18.861   | -39.371  | -80.684  | 17.512            |
| 2                  | 141.289  | 21.969   | -47.616  | -96.984  | 18.650            |
| 3                  | 151.054  | 23.296   | -51.209  | -104.067 | 19.070            |
| 4                  | 156.202  | 23.993   | -53.108  | -107.808 | 19.276            |

**Tab.7 Effect of branch 1 loop number variation on bias current (A)**

| Branch 1 loop number | Branch 1 | Branch 2 | Branch 3 | Branch 4 | Converter station |
|----------------------|----------|----------|----------|----------|-------------------|
| 1                    | 121.545  | 25.921   | -43.664  | -93.031  | 10.745            |
| 2                    | 141.289  | 21.969   | -47.616  | -96.984  | 18.650            |
| 3                    | 149.522  | 20.327   | -49.258  | -98.626  | 21.928            |
| 4                    | 153.780  | 19.469   | -50.116  | -99.484  | 23.648            |
Tab.8 Effect of branch 4 loop number variation on bias current (A)

| Branch 4 loop number | Branch 1 | Branch 2 | Branch 3 | Branch 4 | Converter station |
|----------------------|----------|----------|----------|----------|-------------------|
| 1                    | 138.440  | 19.119   | -50.465  | -83.545  | 24.349            |
| 2                    | 141.289  | 21.969   | -47.616  | -96.984  | 18.650            |
| 3                    | 142.424  | 23.101   | -46.484  | -102.630 | 16.382            |
| 4                    | 143.003  | 23.682   | -45.903  | -105.561 | 15.221            |

5. Conclusion

1) According to the study of converter transformer grouping, the results show that grounding bias current is maximum with full load and 12 converter transformers under complete monopole earth mode. Single-phase converter transformer bias current is maximum with full load and 6 converter transformers under 1/2 monopole earth mode. Therefore, the change of DC bias under 1/2 monopole earth mode is the most serious.

2) The DC bias is the most serious when converter transformer is running under 1/2 monopole earth mode with full load, the AC substations are closer to the grounding electrodes, and the bus feeder length is shorter and the number of loops is larger. It is suggested that in the planning and design stage, the bias current level of the converter can be evaluated according to the above effects. The influence of converter transformer grouping and receiving end power grid structure, reasonable planning and design of the distance between the receiving end power grid substation and grounding electrode, and the length of the feeder and the number of loops of the converter station should be considered.

6. References

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Appendices
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