Research on Operation and Maintenance Strategy of Bias Magnetic Control Device in Zhalute Converter Station

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Abstract. The commissioning of Zhalute-Qingzhou (±800 kV UHVDC) project and the measurement of DC bias control of transformers in Zhalute converter station show that it is difficult to choose the treatment scheme because of the large number and variety of transformers in the converter station, including converter transformers, phase modulator boost transformers and station transformers. Finally, 8 resistive devices were selected to complete the bias current treatment of the Zhalute-Qingzhou UHVDC project delivery network. However, due to the different magnitudes of DC bias currents of various transformers in the converter station, and the failure of any one of the control devices and the direct neutralization of the neutral point of the transformer, the bias current of the transformer will exceed the standard, and there is a hidden danger of the DC bias of the transformer at the converter station. In this paper, the influence of one and two faults on the safety of the faulty branch transformer is calculated, and the operation and maintenance strategy is proposed. It provides a certain technical basis for practical engineering problems and has important reference significance for the operation and maintenance of DC biasing devices.

Introduction

As the first cross-regional UHVDC transmission project in Northeast China Power Grid, the Zhalute-Qingzhou (±800 kV) UHVDC transmission project has a transmission scale of 10 000 MW, which effectively improves the utilization hours of regional thermal power units, promotes the healthy development of clean energy and provides power guarantee for economic development[1].

The converter station is one of the most important components of the DC transmission system, and its equipment quality is related to the safety and reliability of the operation of the DC transmission system. Due to the construction of the Zhalute converter station, when the unipolar operation occurs, the transformer inside the station may be affected by the DC bias current. In addition to four groups of converter transformers, there are also two stations with step-down transformers, two phase modulators with step-up transformers, busbar high reactance, line reactor and so on. Previous studies show that under 2500 A condition, the DC bias current of four converter transformers (common neutral point) in Zhalute is -16.29A. By linear conversion to 6250A, DC bias current at the neutral point of converter transformer will exceed the standard. According to the data of the grid after completion of the project, it is considered that the Zhalute converter station will be connected to more low-potential substations at this time, we adopt the control scheme of converter and converter 2 ohms, boost transformer, substation plus 1 ohm, bus reactor with 3 ohms, 220 kV Fuhe and 220 kV Lubei substations plus 2 ohms. However, the bias current of all transformers in Zhalute converter station will change if any control device fails and the neutral point of transformer is grounded directly. The bias current of the transmission network of Zhalute-Qingzhou project will be redistributed in Zhalute converter station.
At present, there have been related researches on DC bias problems caused by DC transmission at home and abroad. Literature [2] deeply studies the influence of DC bias on transformer and related theoretical problems, analyses the mechanism of DC bias, further quantitatively analyses the changes of transformer operation performance under DC component, and gives the reference value of ordinary transformer withstanding DC bias level. Document [3] analyses the cause and mechanism of DC bias, calculates the excitation current of transformer when DC bias occurs by EMTP software, and further demonstrates the DC current limit allowed to pass through when transformer is running. The causes and mechanism of transformer core overheating, transformer noise increase and transformer temperature rise increase caused by DC bias are studied and analyzed in reference [4]. Taking the main transformer of 500kV Wunan transformer in Jiangsu power grid as an example, the relevant data are measured, and the excitation current, oil temperature and winding temperature rise are calculated quantitatively. Literature [5] studied the influence of converter transformer marshalling and receiving grid structure on DC bias, and analyzed the main factors affecting the severity of DC bias. Literature [6] analyses the problems existing in the UHV straightening device in Xizhe, and puts forward some improvement measures to solve the problems of inappropriate switching and frequent switching by modifying the delay time of switching into the straightening function and increasing the protection setting value of withdrawing from the straightening function. However, there is no relevant research on the influence of the converter station on the bias current in the event of faults and changes in operation mode due to the large number of control devices.

Based on the existing research, this paper analyzes and calculates the impact of one and two faults on the safety of the faulty branch transformer, and proposes the operation and maintenance strategy.

Ground Potential Distribution Calculation

Three-dimensional Earth Resistivity Model

Through the analysis of the geoelectric structure of the polar address, the resistivity data of different regions and depths can be obtained. Based on the resistivity data, a three-dimensional georesistivity model of a cuboid with a length of 400 km and a width of 400 km and an area of 160,000 square kilometers is established. As shown in Figure 1, different color modules in the figure represent different resistivity zones.

![Figure 1. Three-dimensional georesistivity model near Aogan Chaoluga-chu pole site.](image)

Nine-Layer Soil Model Data

In order to design the grounding pole, the Northwest Institute used direct current method and transient electromagnetic method to detect the soil in a small area of the pole site. The resistivity data of the
shallow soil at the pole site were obtained as shown in Table 1. As can be seen from Table 1, the measured resistivity of shallow soil is about 300Ω·m.

| sequence | Depth of start and stop (m) | Range of resistivity (Ω·m) |
|----------|-----------------------------|-----------------------------|
| 1        | 0-2                         | 200-400                     |
| 2        | 2-40                        | 150-300                     |
| 3        | 40-100                      | 35-80                       |
| 4        | 100-200                     | 40-100                      |
| 5        | 200-2000                    | 70-110                      |
| 6        | 2000-2500                   | 25-50                       |
| 7        | 2500-15000                  | 80-150                      |
| 8        | 15000-25000                 | 10-60                       |
| 9        | 25000-30000                 | 1100-1750                   |

**Potential Calculation Results**

Based on the revised three-dimensional earth resistivity model and the operation mode of the power grid of the State Grid Corporation of China (Northeast Branch) in the year of 2017, the distance between the earthing pole and the ground potential distribution of the substations near the earthing pole at the earthing current of 2500A are obtained, as shown in Table 2.

| Voltage level (kV) | Name                  | Distance (km) | Potential (V) | Voltage level (kV) | Name                  | Distance (km) | Potential (V) |
|--------------------|-----------------------|---------------|---------------|--------------------|-----------------------|---------------|---------------|
| 220                | Fuhe                  | 25.08         | 42.890        | 220                | Ganqika              | 206.73        | 0.911         |
| 220                | Lubei                 | 33.55         | 38.050        | 220                | Kulun                 | 217.38        | 0.895         |
|                   | Zhalute               | 42.45         | 35.890        | 220                | Zhalv                 | 166.38        | 0.874         |
|                   | Youzhong              | 36.6          | 22.930        | 500                | Xiangyang            | 123.7         | 0.816         |
|                   | Jingke Power Plant    | 43.4          | 19.880        | 220                | Ulanhada              | 165.1         | 0.786         |
|                   | Zhalute               | 42.45         | 35.890        | 220                | Zhalv                 | 166.38        | 0.874         |
|                   | Youzhong              | 36.6          | 22.930        | 500                | Xiangyang            | 123.7         | 0.816         |
|                   | Jingke Power Plant    | 43.4          | 19.880        | 220                | Ulanhada              | 165.1         | 0.786         |
|                   | Zhalute               | 42.45         | 35.890        | 220                | Zhalv                 | 166.38        | 0.874         |
|                   | Youzhong              | 36.6          | 22.930        | 500                | Xiangyang            | 123.7         | 0.816         |
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|                   | Zhalute               | 42.45         | 35.890        | 220                | Zhalv                 | 166.38        | 0.874         |
|                   | Youzhong              | 36.6          | 22.930        | 500                | Xiangyang            | 123.7         | 0.816         |
|                   | Jingke Power Plant    | 43.4          | 19.880        | 220                | Ulanhada              | 165.1         | 0.786         |
|                   | Zhelinmu              | 133.81        | 4.385         | 220                | Liun                  | 190           | 0.400         |
|                   | Hoqin                 | 136.32        | 4.348         | 220                | Baicheng             | 187.47        | 0.365         |
| 500                | Tongliao Power Plant  | 129.77        | 4.609         | 220                | Lindong               | 195           | 0.516         |
| 220                | Hexi                  | 143.51        | 4.482         | 220                | Baicheng Thermal     | 156           | 0.474         |
| 220                | Zhelinmu              | 133.81        | 4.385         | 220                | Liun                  | 190           | 0.400         |
| 500                | Horqin                | 136.32        | 4.348         | 220                | Baicheng             | 187.47        | 0.365         |
| 220                | Tongliao Power Plant  | 141.62        | 4.040         | 220                | Hailutu               | 231.39        | 0.320         |
Because the electric property and structure of the earth will not change in a short time, the ground potential of the ground electrode is proportional to the ground current, that is, the ground potential of the ground electrode is doubled when the ground current of the ground electrode is doubled, and the potential value of other working conditions can be converted by proportion.

**Effect of Device Failure on Safety of Faulty Branch Transformer**

**Standards and Algorithms for DC Current Model of Power Grid**

Using the "GIC-Benchmark" standard led by EPRI in 2012, the "GIC-Benchmark" standard is shown in Figure 2. Through 20 buses, 15 lines, 7 substations, 1 switching station and 15 transformers, the method of building quasi-DC GIC grid model is given [7]. The standard is also applicable to the establishment of DC current model for grounding electrode reason. The blue part is high voltage (345kV) transmission line and the red part is ultrahigh voltage (500kV) transmission line. GIC-Benchmark standard also considers different winding connection modes, different types of
transformer combinations, single (double) circuit transmission lines, series compensation and grounding capacitors to interrupt magnetic bias current flow equipment and impact.

Figure 2. Representation of GIC-benchmark standard by single phase connection diagram.

The transformers in practical calculation are all treated as autotransformers, and their single-phase equivalent circuits and models are shown in Fig. 3. The nodal admittance method is used to calculate the equivalent model as shown in Fig. 4. In Figure 4, I, j, m, n, p, q are arbitrary nodes in the grid, $y_{i0}$ and $y_{j0}$ are grounding branch admittances of grounding nodes, $I_{i0}$ and $I_{j0}$ are equivalent current sources of node i and j, and $I_{i0} = u_{i0}y_{i0}$, $I_{j0} = u_{j0}y_{j0}$, where $u_{i0}$ and $u_{j0}$ are respectively node i and j grounding point potential.

Figure 3. Single-phase equivalent circuit and model of bias current of autotransformer.

Figure 4. Calculation model of magnetic bias current based on nodal admittance matrix method.

For any node i, the nodal admittance matrix equation is:
\[ i_i = u_iy_{ii} - \sum_{k=1, k \neq i}^{n} u_ky_{ki} \]  

(1)

In formula \( i_i \) is the injection current of node \( i \). For grounding node \( i = i_0 \) and for non-grounding node \( i_0 = 0 \). Let the admittance matrix of network node be \( Y \), the diagonal element \( Y_{ii} \) is self-admittance, and the non-diagonal element \( Y_{ij} \) is mutual admittance. The values are as follows:

\[ Y_{ii} = y_{i0} + \sum_{j=1}^{N} y_{ij}, j \neq i \]  

(2)

\[ Y_{ij} = Y_{ji} = -y_{ij} = -y_{ji} \]  

(3)

Formula (1) can be rewritten as

\[ i_i = \sum_{k=1}^{n} u_kY_{ki} \]  

(4)

The matrix form is

\[ I = YU \]  

(5)

The node voltage matrix can be obtained:

\[ U = Y^{-1}I \]  

(6)

The bias current of each branch is calculated according to the calculated node voltage.

**Calculation of Bias Current of Branch after Device Failure**

Transformer parameters are selected from Volume 2 and Table 3 of "Preliminary Design of Ground Pole for Zhalute ±800 kV UHVDC Converter Station in Zhalute-Qingzhou ±800 kV UHVDC Transmission Project" of Northwest Electric Power Design Institute.

**Table 3. Typical values of grid parameters at different voltage levels.**

| Voltage level /kV | Grounding Resistance of Substation /Ω | DC Resistance of Transformer Windings/Ω | DC Resistance per Unit Length of Line /Ω |
|-------------------|--------------------------------------|----------------------------------------|----------------------------------------|
|                   |                                      | High Voltage Winding | Medium Voltage Winding |                         |
| 500               | 0.2                                  | 0.238                    | 0.097                    | 0.0187                  |
| 220               | 0.3                                  | 0.451                    |                         | 0.039                   |

The transformers in Zhara converter station have high busbar reactance and high line DC resistance as shown in Tables 4 and 5.

**Table 4. Transformer parameters of converter station.**

| Type of transformer | Single-phase winding resistance /Ω | Grounding resistance /Ω | Number |
|---------------------|-----------------------------------|-------------------------|--------|
| Converter transformer | 0.164                            | 0.2                     | 4      |
| Station step-down transformer | 0.70                             | 0.2                     | 2      |
| Phase Regulator Boost Transformer | 1.05045                          | 0.2                     | 2      |
Table 5. Reactor parameters.

| High resistance type | Single-phase DC resistance /Ω | DC Resistance of Neutral Point Small Reactor /Ω |
|----------------------|------------------------------|---------------------------------------------|
| Bus bar high reactance | 1.6333                       | 0.2                                         |
| Line High Reactance  | 3.2963                       | 9.667+0.2                                   |

According to nodal admittance method, the bias current of transformer neutral points is calculated when one or two faults occur in the treatment device of Zalut converter station. The results are shown in tables 6 and 7. The calculated current value is the three-phase value of a single transformer. The transformer inflow into the earth is positive and the earth inflow into the transformer is negative.

Table 6. The bias current of the neutral point of each transformer in the failure of one device of the Zhalute converter station.

| Fault Types of Devices | Converter non-fault branch | Converter fault branch | Station Variable Non-fault Branch | Station Variable Fault Branch | Boost transformer non-fault branch | Boost transformer fault branch | Busbar Reactor | Line reactor | Branch of 500 kV Longfeng Station |
|------------------------|-----------------------------|------------------------|-----------------------------------|-------------------------------|-----------------------------------|-------------------------------|----------------|-------------|----------------------------------|
| No malfunction of treatment device | -8.57                       | /                      | -16.02                            | /                             | -15.46                            | /                             | -9.95          | -3.29       | 10.86                            |
| Fault of Converter Transformer Device | -1.22                       | -134.99                | -2.28                             | /                             | -2.20                             | /                             | -1.42          | -0.47       | 18.59                            |
| Station transformer failure | -5.19                       | /                      | -132.73                           | -9.58                         | -9.37                             | /                             | -6.03          | -1.99       | /                                |
| Fault of Boost Transformer Device | -6.03                       | /                      | -11.28                            | /                             | -103.27                           | -0.66                         | -7.01          | -2.32       | /                                |
| Bus Reactor Fault      | -6.74                       | /                      | -12.59                            | /                             | -12.15                            | /                             | -74.50         | -2.59       | /                                |

Table 7. The bias current of the neutral point of each transformer in the failure of two devices of the Zhalute converter station.

| Fault Types of Devices | Converter non-fault branch | Converter fault branch | Station Variable Non-fault Branch | Station Variable Fault Branch | Boost transformer non-fault branch | Boost transformer fault branch | Busbar Reactor | Line reactor | Branch of 500 kV Longfeng Station |
|------------------------|-----------------------------|------------------------|-----------------------------------|-------------------------------|-----------------------------------|-------------------------------|----------------|-------------|----------------------------------|
| No malfunction of treatment device | -8.57                       | /                      | -16.02                            | /                             | -15.46                            | /                             | -9.95          | -3.29       | 10.86                            |
| Two Faults of Converter Transformer Device | /                           | -72.66                | -1.23                             | /                             | -1.18                             | /                             | -0.76          | -0.25       | 19.18                            |
| Two Faults of Station Transformer Devices | -3.75                       | /                      | /                                 | -94.68                        | -6.77                             | /                             | -4.36          | -1.44       | /                                |
| Two Faults of Boost Transformer Device | -4.67                       | /                      | /                                 | /                             | /                                 | -79.32                       | -5.43          | -1.79       | /                                |
| Faults of Converter Transformer and Station Transformer | Faults of Converter Transformer and Boost Transformer Fault of High Reactance Device of One Converter Transformer and Bus Line Faults of one transformer and one boost transformer for station Fault of High Reactance Device of One Transformer and Bus Bus for Station Fault of High Reactance Device of One Boost Transformer and Bus Line |
|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| -1.12 -123.57 -2.06 -28.51 -2.01 / -1.30 -0.43 18.70 | -1.09 -120.69 -2.04 / -0.12 -33.48 -1.27 -0.42 18.73 |
| -1.17 -129.97 -2.19 / -2.12 / -12.97 -0.45 18.64 | -4.14 / -7.63 -105.79 -0.45 -70.83 -4.81 -1.59 / |
| -4.46 / -8.22 -113.96 -8.04 / -49.30 -1.71 / | -5.07 / -9.47 / -5.30 -86.67 -56.00 -1.94 / |

Through calculation, it can be concluded that the bias current of the fault branch will increase when a device fault occurs and the neutral point of the transformer is directly grounded. The maximum case is -134.99A when the converter control device fails. Due to the fault treatment device, the DC resistance of the fault branch decreases, the current shunt increases, and the bias current exceeds the standard. At the same time, it can be found that the DC bias current of 500 kV Longfeng Station will also exceed the standard when the converter control device fails. When two devices fail, the biased magnetic current of the fault branch will also exceed the standard. At this time, the two fault branches have large shunts, which will cause the biased magnetic current to exceed the standard. Moreover, when the converter control device fails, the DC biased magnetic current of 500 kV Longfeng Station will also exceed the standard. At this time, the most serious case of bias current is that when a converter and bus high reactance device fail, the bias current of the converter fault branch is -129.97A.

**Effect of Device Failure on Safety of Faulty Branch Transformer**

Because there may be one or two faults in the transformer bias control device of the converter station, and the probability of three faults is small, the bias current values of each branch of the converter station when one or two faults occur are calculated and analyzed in the preceding paper. The calculation shows that the fault of the magnetic bias control device will cause the magnetic bias
current of the fault branch to exceed the standard, and the treatment will fail. Therefore, this paper proposes several operational and maintenance strategies:

(1) The average service life of the treatment device can be evaluated by life test, and the reasonable maintenance period can be set according to the reliability index, and the reliability of the treatment device can be periodically overhauled. It should be pointed out that life test is destructive test, and the disadvantage of this strategy is uneconomical.

(2) Adding a standby magnetic bias control device, when the HVDC system operates in a single-to-great way and detects that the DC current flowing through the neutral point of the transformer exceeds the limit, the fault of this branch device can be preliminarily determined. At this time, disconnect the branch magnetic bias control device and switch to the standby magnetic bias control device to prevent the fault branch magnetic bias current exceeding the standard.

(3) Considering the resistance of transformer neutral point, the series connection method can be used to reduce the harm caused by the device failure.

Summary

This paper analyses and calculates the value of branch bias current of transformer in Zharut converter station when one and two faults occur. Through the analysis of all the cases, it can be concluded that the shunt of bias current increases due to the decrease of resistance value of fault branch, and the danger of current exceeding the standard exists. The relevant operation and maintenance strategies are put forward, which provides technical basis for the formulation of solutions to engineering problems caused by the faults of bias devices. The main conclusions are as follows:

(1) When a device failure occurs, the bias current of the fault branch increases when the neutral point of the transformer is directly grounded. The maximum case is -134.99A when the converter control device fails. Due to the fault treatment device, the DC resistance of the fault branch decreases, the current shunt increases, and the bias current exceeds the standard. At the same time, it can be found that the DC bias current of 500 kV Longfeng Station will also exceed the standard when the converter control device fails.

(2) When two devices fail, the biased magnetic current of the fault branch will also exceed the standard. At this time, the two fault branches have large shunts, which will cause the biased magnetic current to exceed the standard. Moreover, when the converter control device fails, the DC biased magnetic current of 500 kV Longfeng Station will also exceed the standard. At this time, the most serious case of bias current is that when a converter and bus high reactance device fail, the bias current of the converter fault branch is -129.97A.

(3) For the magnetic bias control device, the maintenance cycle can be established and regular maintenance can be carried out, but the maintenance cycle is not well determined.

(4) The standby magnetic bias control device can be added to prevent the branch current from exceeding the standard due to the fault of the device. However, the increase in the number of treatment devices used in this method will increase the cost.

(5) According to the resistance value of transformer neutral point, several magnetic bias current control devices with smaller resistance value can be connected in series to reduce the harm caused by device failure.

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