Optimized Neutral Point Connection Mode
Configuration against DC Bias of 220kV Power
Transformation in Yichang Power Grid

Keji Chen, Qianwen Guo, Jiangtao Quan, Ruiji Yu, Tao Wang, Yayun Luo, Jinwen Sun, Xiangning Lin

Abstract—The occurrence of DC Bias will affect the normal operation of power transformer, thus DC bias withstand capability of transformer neutral point in Yichang area is established. Meanwhile, according to the transformer noise limit, the maximum current which is allowable to flow through transformer neutral point is determined. On this basis, an optimization configuration of neutral point connection mode is proposed to inhibit DC bias. Since the change of zero sequence impedance, at last we give sensitivity verification of zero sequence current protection base on the RelayCAC model of Yichang power grid. Simulation results show that the sensitivity meet the requirements and verify the effectiveness of the proposed method.

Index Terms—DC Bias, neutral point connection mode, noise, zero sequence current protection, sensitivity verification

I. INTRODUCTION

With the formation of AC-DC hybrid transmission mode in China, issues of mutual interference in AC-DC system is appearing. If HVDC transmission system is in the unipolar - earth or bipolar imbalance operating conditions, the DC current flowing into the earth through grounding electrode will impact on power equipment of AC power system. The DC current will flow into the transformer winding and the DC bias occurs, causing the main transformer harmonics, noise, overheating and other issues, which may lead to serious damage of the transformer and the capacitor, affecting the safe operation of the power grid.

In this paper, we establish the DC current distribution model of transformer neutral point in Yichang area. Meanwhile, according to the transformer noise limit, the maximum current which is allowable to flow through transformer neutral point is determined. On this basis, an optimization of neutral point connection mode configuration is proposed to inhibit DC bias. Through simultaneous grounding of two transformer neutral points in one substations, the DC bias current through each neutral point was reduced. In the last of this paper, considering that the change of neutral point connection mode will eventually lead to the change of system’s zero-sequence parameters, the setting values and sensitivity verification of zero-sequence current protection after optimization were calculated based on the RelayCAC model of Yichang power grid.

II. DC CURRENT DISTRIBUTION OF TRANSFORMER NEUTRAL POINT IN YICHANG POWER GRID

A. DC Current Distribution Model

Considering that there are m substations, k independent neutral points, and x bus nodes, according to the node voltage method:

\[ YV = J \]

(1)

Where Y stands for the nodal-admittance matrix of the power network, \( Y = HG + Q \). H denotes the incident matrix between the nodes of substations and all nodes, HT is the transpose matrix of H, \( H = [E \ 0 \ 0] \). E means unit matrix of m-order, 0 stands for zero matrix; G means the grounding conductance matrix of the substations, \( G = R^2 \), \( R = \text{diag} (R_{1G}, R_{2G}, \ldots, R_{mG}) \), \( R_{iG} \) stands for the equivalent resistance of the substation i, scilicet the input resistance between neutral point and zero point. Q denotes the nodal-admittance matrix of the AC network. V means the column vector of the node voltage, \( V = [V_S \ V_N \ V_B] \). \( V_S \), \( V_N \) and \( V_B \) mean the node voltage of the substation, the neutral point voltage and voltage column vector of the bus. J denotes the injected current column vector of the nodes.

\[ J = [J_S \ J_N \ J_B] \]

(2)

Where \( J_S \), \( J_N \) and \( J_B \) stand for nodes’ current column vector of substation nodes, neutral point and bus nodes respectively; \( P \) stands for the inductive potential column vector of...
substations, silicon the entrance potentials between the neutral points and the zero points.

\[ P = M \Delta I_{DC} + N \Delta I_{AC} \]  \hspace{1cm} (3)

Where \( M \) means the mutual resistance matrix between DC poles and substations; \( N \) means the mutual resistance matrix between the substations (with no self-reaction considered); \( I_{DC} \) means the earth DC current of DC transmission system; \( I_{AC} \) means the earth current column vector of the neutral points in substations.

\[ I_{AC} = G (V_S - P) \]  \hspace{1cm} (4)

\[ V_S = HV \]  \hspace{1cm} (5)

Combine equations (1)–(5), it can be concluded that:

\[ (R - Z_N) I_{AC} = Z_M \Delta I_{DC} \]  \hspace{1cm} (6)

Where \( Z = HY^2H^T \). Solve equation (6) for \( I_{AC} \). Then the voltages of nodes are described below:

\[ V = Y^T H (M \Delta I_{DC} + N \Delta I_{AC}) \]  \hspace{1cm} (7)

The DC current distribution of the transformer neutral points in the entire AC network can be acquired through (1)–(7).

**B. DC Current of Transformer Neutral Point Distribution in Yichang Region**

This paper only focuses on 8 substations that are rather close to their surrounding residential areas in Yichang region. That is substations Gujiadian, Xiaoting, Baijiachong, Zhijiang, Guojiajagang, Changyang, Chezhan and Yangjiawan. Under routine operation mode, transformer neutral current parts of Yichang region are calculated according to system parameters and Equation (1)–(7). The results are shown in Table I.

**TABLE I. DC CURRENT OF TRANSFORMATION NEUTRAL POINT DISTRIBUTION IN YICHANG POWER GRID**

<table>
<thead>
<tr>
<th>Substation</th>
<th>DC current of transformer neutral point (A)</th>
<th>Substation</th>
<th>DC current of transformer neutral point (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gujiadion</td>
<td>3.522</td>
<td>Guojiajagang</td>
<td>-5.651</td>
</tr>
<tr>
<td>Xiaoting</td>
<td>-2.383</td>
<td>Changyang</td>
<td>3.319</td>
</tr>
<tr>
<td>Baijiachong</td>
<td>7.663</td>
<td>Chezhan</td>
<td>1.660</td>
</tr>
<tr>
<td>Zhijiang</td>
<td>1.503</td>
<td>Yangjiawan</td>
<td>-9.490</td>
</tr>
</tbody>
</table>

**III. OPTIMIZED NEUTRAL POINT CONNECTION MODE CONFIGURATION**

**A. Neutral Point Current Limit**

The DC current limit of the transformer neutral point usually can be determined from the local overheating limits, the vibration limits and the noise limits of the core, the windings and other structural parts. In this paper, the DC bias endurance is determined based on the noise limits.

The noise of the transformer is mainly caused by the core magnetostriction. Under the effect of periodically changing magnetic field, the silicon steel sheet will vibrate and thus generating noises. Since the vibration caused by the magnetostriction is nonsinusoidal, the noise spectrum contains lots of harmonic components, and the noise increases with the magnetic flux density. The correlating equation of the magnetic flux density and the noise can be described as follow:

\[ \Delta L = 10 \log \left( \frac{B_2}{B_1} \right) \]  \hspace{1cm} (8)

According to the actual parameters of the 220kV transformer, with the transformer neutral point DC current changing from 0 to 15A (step size of 0.5A), the core flux variation was simulated, and the relevant data exported. Using Matlab fitting, the transformer neutral point current and the noise can be described as a function of Equation (10) and Fig.1 shows the relationship between noise and DC current of transformer neutral point.

\[ L = 54.4085 \log(i + 10) + 15.0217 \]  \hspace{1cm} (10)

**Fig 1. Relationship between noise and DC current of transformer neutral point**

According to the measurement statistic research of Hubei Electric Power Research Laboratory, when the transformer substation noise exceeds 80 decibels, it will affect the daily routine of the surrounding residents, which suggests that the neutral point current limit is 6.2A.

**B. Optimization Scheme**

As is shown in Fig.2, \( T_{i1} \) and \( T_{i2} \) is the two transformers which is belonged to substation \( i \) and \( T_{j1} \) and \( T_{j2} \) belonged to substation \( j \). \( R_i \) (\( s = 1, 2, 3, ..., N \)) stands for AC transmission line resistance and \( R_{ij} \) (\( i, j = 1, 2, 3, ..., N \)) reflects the effect of soil resistance in DC current circulation between transformer substation \( i \) and \( j \).

When it is in the daily operation, there are two transformers put into use in the 220kV substation of Yichang. One of which has its neutral point directly grounded while the other’s is gap grounded, such as the transformer substation \( j \) shown in Fig.2. Under this circumstance, if the DC transmission line is monopole operating, the neutral current of transformer would get over standard and cause DC bias. To solve the problem, this paper proposes a new measure of inhibiting DC bias by optimizing the connection mode of neutral points. Grounding simultaneously both transformers of the substation (such as...
the substation i shown in Fig.2) which has over proof neutral current would reduce the neutral current in each transformer.

C. Optimization Resluts

According to the Table I, the transformer neutral point current of Yangjiawan is -9.490A, and that of Baijiachong is 7.663A, both exceed the limit of 6.2A. Therefore, make the neutral points of two transformers in Yangjiawan and Baijiachong substation simultaneously grounded. The optimization results are shown in Table II.

Table II. Optimization Results

<table>
<thead>
<tr>
<th>Substation</th>
<th>DC current of transformer neutral point (A)</th>
<th>Substation</th>
<th>DC current of transformer neutral point (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guojiadian</td>
<td>2.848</td>
<td>Guojiagang</td>
<td>-6.078</td>
</tr>
<tr>
<td>Xiaoting</td>
<td>-3.065</td>
<td>Changyang</td>
<td>3.229</td>
</tr>
<tr>
<td>Baijiachong</td>
<td>5.429</td>
<td>Chezhan</td>
<td>1.614</td>
</tr>
<tr>
<td>Zhijiang</td>
<td>1.408</td>
<td>Yangjiawan</td>
<td>-5.134</td>
</tr>
</tbody>
</table>

From Table II, we can see that all transformer’s neutral point current is under 6.2A, thus meeting the standard of transformer noise limit.

IV. SENSITIVITY VERIFICATION OF ZERO SEQUENCE CURRENT PROTECTION

A. RelayCAC Model of Yichang Power Grid

![Fig 3. RelayCAC model of Yichang power grid](image)

It has been proved in the last chapter that grounding simultaneously of two transformer neutral points in one substation is an effective method to inhibit DC bias. But the zero-sequence parameters of the system would change. To go a step further and test how grounding both transformers can influence the sensitivity of zero-sequence current protection, we can take the power network of Yichang as an example and use RelayCAC to test it after optimizing the neutral connection mode. The RelayCAC model of Yichang power grid is shown in Fig.3.

B. Setting Principles of Zero Sequence Current Protection

According to the zero sequence current protection setting principles of the Central China region, based on the actual operation situation of the Yichang power grid, the zero sequence current protection configurations and applications of it can be properly simplified, keeping only the zero sequence Segment IV against high-resistance-grounding fault, with the other three segments set as out of the operation, while the current and time setting values must be set in accordance with the largest scale.

The setting principles of zero sequence current protection Segment IV are as follows:

- Guarantee sensitivity of the line end faults:
  \[ I_{\text{dzt}} = 3 \times I_{\text{imin}} / K_{\text{lm}} \]

  Where, \( K_{\text{lm}} \) is the sensitivity coefficient. For lines under 50km, \( K_{\text{lm}} \) equals 1.5; for lines between 50km and 200 km, \( K_{\text{lm}} \) equals 1.4 ; for lines over 200km, \( K_{\text{lm}} \) equal 1.3; \( I_{\text{imin}} \) is the minimum zero sequence current flowing through this protection during the line end fault.

- Fixed value avoiding high-resistance-grounding fault
  \[ I_{\text{dzt}} = 300 \text{A} \]

- Avoid maximum load imbalance current
  \[ I_{\text{dlt}} = K_{\text{bp}} \times I_{\text{loadmax}} \]

  Where, \( K_{\text{bp}} = 0.1 \); \( I_{\text{loadmax}} \) is the maximum load current of the line.

  When 300A is between \( I_{\text{dlt}} \) and \( I_{\text{dzt}} \), the fixed value can be set as 300A. If \( I_{\text{dlt}} \geq I_{\text{dzt}} \), set it as \( I_{\text{dzt}} \), otherwise \( I_{\text{dlt}} \).

C. Verification Results

The calculation results are shown in Table III.

Table III. Setting Results

<table>
<thead>
<tr>
<th>Lines</th>
<th>Before optimization</th>
<th>After optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( I_{\text{set}} ) (kA)</td>
<td>Time(s)</td>
</tr>
<tr>
<td>Bai-Xiao I (Side Bai)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Bai-Xiao I (Side Xiao)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Bai-Xiao II (Side Bai)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Bai-Xiao II (Side Xiao)</td>
<td>1.995</td>
<td>4.5</td>
</tr>
<tr>
<td>Ge-Bai (Side Ge)</td>
<td>6.355</td>
<td>4.5</td>
</tr>
<tr>
<td>Ge-Bai (Side Xiao)</td>
<td>1.842</td>
<td>4.5</td>
</tr>
<tr>
<td>Ge-Bai II (Side Ge)</td>
<td>4.527</td>
<td>4.5</td>
</tr>
<tr>
<td>Ge-Bai II (Side Bai)</td>
<td>1.631</td>
<td>4.5</td>
</tr>
<tr>
<td>Long-Wan I (Side Wan)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Long-Wan I (Side Long)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Long-Wan II (Side Wan)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Long-Wan II (Side Long)</td>
<td>0.296</td>
<td>4.5</td>
</tr>
<tr>
<td>Wan-Tong (Side Wan)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Wan-Tong (Side Tong)</td>
<td>0.3</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Where, \( I_{\text{set}} \) stands for the setting results before optimization and \( I_{\text{lm}} \) stands for the setting results after optimization. \( K_{\text{lm}} \) is the sensitivity coefficient in the present operation mode. If \( I_{\text{set}} / I_{\text{set}} \geq I_{\text{lm}} / I_{\text{lm}} \), sensitivity meets the requirement. Thus the sensitivity verification criterion of zero-sequence current protection is \( I_{\text{set}} > I_{\text{set}} \). Seen from Table III, the setting results meet the requirements of sensitivity verification criterion.

V. CONCLUSION

In this paper, a DC current transformer neutral point distribution model in Yichang was established to help determining the maximum current through the transformer neutral point under the transformer noise limits, and on this
basis, a configuration of neutral point connection mode optimization was proposed to inhibit DC bias. Sensitivity verification of zero sequence current protection is given based on the RelayCAC model of Yichang power grid. Simulation results show that the sensitivity meet the requirements and verify the effectiveness of the proposed method. The relevant conclusions provide an important reference for further research of suppression measures against DC bias.

REFERENCES


