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 is a prerequisite for stable operation of power system. In this paper, the DC current distribution model 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 substation, 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.

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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:

$$YV=J \tag{1}$$

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^{-1}, R＝diag（R_{1G}，R_{2G}，…，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.

$$J=[J_S\ J_N\ J_B]=[GP\ 0\ 0]=H^TGP \tag{2}$$

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

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substations, scilicet the entrance potentials between the neutral points and the zero points.

$$P = MI_{DC} + NI_{AC} \quad (3)$$

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.

$$I_{AC} = G(V_S - P) \quad (4)$$

$$V_S = HV \quad (5)$$

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

$$(R - Z_N) I_{AC} = Z_M I_{DC} \quad (6)$$

Where $Z = HY^{-1}H^T G - E$. Solve equation (6) for I_{AC}. Then the voltages of nodes are described below:

$$V = Y^{-1}HG(MI_{DC} + NI_{AC}) \quad (7)$$

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 substation Gujiadian、Xiaoting、Baijiachong、Zhijiang、Guojiagang、Changyang、Chezhan and Yangjiawan. Under routine operation mode, transformer neutral point currents 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

Substation	DC current of transformer neutral point (A)	Substation	DC current of transformer neutral point (A)
Gujiadian	3.522	Guojiagang	-5.651
Xiaoting	-2.383	Changyang	3.319
Baijiachong	7.663	Chezhan	1.660
Zhijiang	1.503	Yangjiawan	-9.490

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:

$$\Delta L = 10\log[(\frac{B_2}{B_1})] \quad (8)$$

$$L = L_B + \Delta L \quad (9)$$

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.

$$L = 54.4085\lg(i + 10) + 15.0217 \quad (10)$$

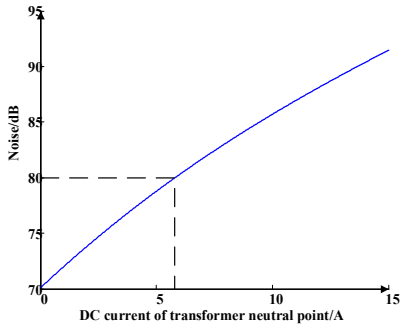

Fig 1. Relationship between noise and DC current of transformer neutral point

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

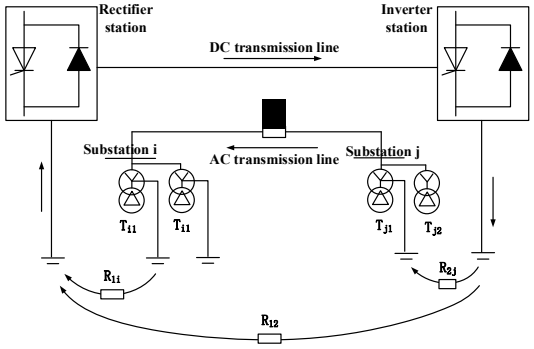

Fig 2. Schematic of optimization scheme

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_s (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

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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 resluts are shown in Table II.

Table II. Optimization Reluts

Substation	DC current of transformer neutral point (A)	Substation	DC current of transformer neutral point (A)
Gujiadian	2.848	Guojiagang	-6.078
Xiaoting	-3.065	Changyang	3.229
Baijiachong	5.429	Chezhan	1.614
Zhijiang	1.408	Yangjiawan	-5.134

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

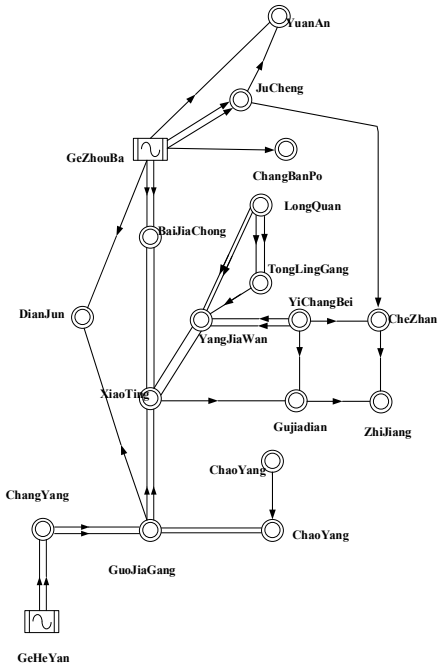

Fig 3. RelayCAC model of Yichang power grid

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 influent 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:

$$I_{dz1}= 3*I_{0min}/K_{lm}$$

Where, K_{lm} is the sensitivity coefficient. For lines under 50km, K_{lm} equals 1.5; for lines between 50km and 200 km, K_{lm} equals 1.4 ; for lines over 200km，K_{lm} equal 1.3; I_{0min} is the minimum zero sequence current flowing through this protection during the line end fault.

Fixed value avoiding high-resistance-grounding fault

$$I_{dz2}=300A$$

Avoid maximum load imbalance current

$$I_{dz3}=K_{bp}\times I_{loadmax}$$

Where, $K_{bp}=0.1$; $I_{loadmax}$ is the maximum load current of the line.

When 300A is between I_{dz1} and I_{dz3}, the fixed value can be set as 300A. If $I_{dz1}>I_{dz3}$, set it as I_{dz1}, otherwise I_{dz3}.

C. Verification Results

The calculation results are shown in Table III.

Table III. Setting Results

Lines	Before optimization		After optimization	
	I_{set} (kA)	Time(s)	I_{im} (kA)	Time(s)
Bai-Xiao I (Side Bai)	0.3	4.5	0.3	4.5
Bai-Xiao I (Side Xiao)	0.3	4.5	0.3	4.5
Bai-Xiao II(Side Bai)	0.3	4.5	0.3	4.5
Bai-Xiao II (Side Xiao)	1.995	4.5	0.3	4.5
Ge-Bai I(Side Ge)	6.355	4.5	6.457	4.5
Ge-Bai I(Side Bai)	1.842	4.5	2.436	4.5
Ge-Bai II(Side Ge)	4.527	4.5	4.599	4.5
Ge-Bai II(Side Bai)	1.631	4.5	1.842	4.5
Long-Wan I (Side Wan)	0.3	4.5	0.3	4.5
Long-Wan I (Side Long)	0.3	4.5	0.3	4.5
Long-Wan II (Side Wan)	0.3	4.5	0.3	4.5
Long-Wan II (Side Long)	0.296	4.5	0.296	4.5
Wan-Tong(Side Wan)	0.3	4.5	0.3	4.5
Wan-Tong(Side Tong)	0.3	4.5	0.3	4.5

Where, I_{set} stands for the setting results before optimization and I_{im} stands for the setting results before optimization，K_{lm} is the sensitivity coefficient in the present operation mode. If $I_{cur}/I_{set}> I_{cur}/I_{im} =K_{lm}$, sensitivity meets the requirement. Thus the sensitivity verification criterion of zero-sequence current protection is $I_{im}>I_{set}$. 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

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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.

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