Actual Measurement and Analysis of DC Magnetic Bias of 750kv Autotransformer

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Abstract. Monopole to ground operation mode of ultra high-voltage DC transmission system will result in DC magnetic biasing phenomenon to transformers in surrounding AC substation. Under monopole to ground operation mode of ±800kV “Qi-Shao” ultra high-voltage DC transmission project, DC magnetic biasing hazard of transformers in AC power network in sending terminal—Jiuquan region was tested. It’s found that after capacitive DC blocking device of 750kV transformer neutral point was put into action, transformer vibration and noise still gradually increased with ground current at ground electrode, so ideal governance effect was not reached. Regional DC current distribution after series capacitance at transformer neutral point in 750kV Dunhuang substation was analyzed in this paper. It’s found that DC current could still flow through autotransformer winding so as to make the transformer be still influenced by DC magnetic bias. Meanwhile, based on analysis of secondary-side waveforms at neutral point of 750kV autotransformer, it’s found that transformer magnetizing current went through serious distortion with current increase at ground electrode after action of DC blocking device. Harmonic analysis was conducted for distorted waveforms and change features of secondary harmonics were used, which provided a convenient and effective means of monitoring DC magnetic biasing hazard of 750kV autotransformer.

1. Introduction

Monopole to ground operation mode of ultra high-voltage DC transmission system will result in DC magnetic biasing phenomenon to transformers in surrounding AC substation. Under monopole to ground operation mode of ±800kV “Qi-Shao” ultra high-voltage DC transmission project, DC magnetic biasing hazard of transformers in AC power network in sending terminal—Jiuquan region was tested. It’s found that after capacitive DC blocking device of 750kV transformer neutral point was put into action, transformer vibration and noise still gradually increased with ground current at ground electrode, so ideal governance effect was not reached. Regional DC current distribution after series capacitance at transformer neutral point in 750kV Dunhuang substation was analyzed in this paper. It’s found that DC current could still flow through autotransformer winding so as to make the transformer be still influenced by DC magnetic bias. Meanwhile, based on analysis of secondary-side waveforms at neutral point of 750kV autotransformer, it’s found that transformer magnetizing current went through serious distortion with current increase at ground electrode after action of DC blocking device. Harmonic analysis was

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conducted for distorted waveforms and change features of secondary harmonics were used, which provided a convenient and effective means of monitoring DC magnetic biasing hazard of 750kV autotransformer.

2. Measuring results of DC magnetic bias

2.1. DC current at neutral point

750kV autotransformer was generally a single-phase transformer, and three-phase neutral point was connected to neutral point bus after being led out and then directly grounded through neutral point bus. High-precision anti-interference Hall coil could be used to measure DC current flowing in (out of) transformer winding in ground lead of neutral point bus. Test data of Dunhuang substation are seen in Table 1, where DC blocking devices at No. 1 and No. 2 transformer neutral points are both under action during the second test process, and the current under action is 5.1A, and DC current at neutral point after action is zero.

Table 1. DC current test at neutral point in 750kV Dunhuang substation.

Ground current at ground electrode (A)	The first test(A)		The second test(A)	
	No.1 transformer	No.2 transformer	No.1 transformer	No.2 transformer
500	-11.7	-13.6	-5.1	-5.1
1000	-22.8	-23.2	0	0
1500	-37.2	-33	0	0

2.2. Vibration and noise test

Maximum values of vibration and noise of phase A of No. 1 transformer and phase A of No. 2 transformer in Dunhuang substation are seen in Table 2. Although capacitive DC blocking devices at neutral points of two main transformers in Dunhuang substation could both conduct action when 500A current was grounded at ground electrode, vibration amplitude and noise amplitude still gradually increased as DC load increased. Vibration amplitudes of No. 1 and 2 transformers increased by about 3 times and noise levels all exceeded enterprise standard 80dB under 5,000A condition. Meanwhile, operation and maintenance personnel in Dunhuang substation judged through ears that transformer noise obviously increased compared with normal operation.

Table 2. Vibration and noise data of Dunhuang substation in the second test.

Ground electrode Idc/A	750kV Dunhuang substation			
	Phase A of No. 1 transformer		Phase A of No. 2 transformer	
	Vibration(um)	Noise (dB)	Vibration(um)	Noise (dB)
500	13.6	79.7	14.0	78.4
1500	22.8	81.0	22.7	82.8
2500	30.7	90.5	44.2	91.2
3250	44.8	94.3	42.4	96.8
5000	48.5	96.2	49.8	98.5

3. Analysis of DC current distribution after action of capacitive DC blocking device

3.1. DC current distribution model

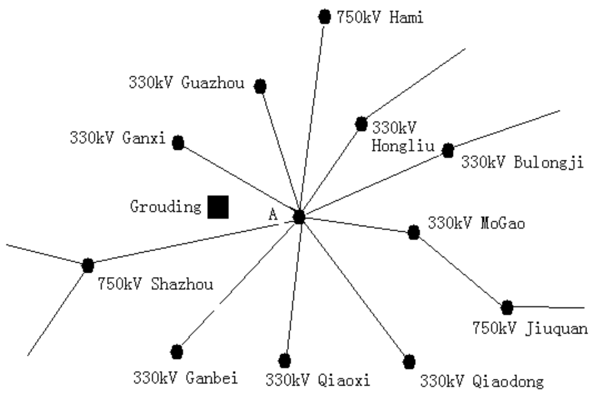

Figure 1. Dunhuang substation—centered regional power network structure.

Regional power network structure is shown in Fig. 1. There were two main transformers in 750kV Dunhuang substation, their windings consisted of series winding and common winding, and high-voltage side was let out from bus export of series winding while medium-voltage side was led out between series winding and common winding. 66kV low-voltage side was triangular wiring structure without DC current flowing through the winding, so it was not taken into consideration. 330kV transformer winding structure in Jiuquan region was also auto-coupling form but as 110kV transformers in this region were all ungrounded systems, 110kV medium-voltage side of 330kV transformer might not be considered during analysis of DC current distribution under monopole to ground operation mode of regional DC transmission system. In consideration of transformer windings of substations, DC current distribution model of Dunhuang substation—centered regional power network is shown in Fig. 2, where Rc1 and Rc2 are series windings of autotransformer, and Rg1 and Rg2 are common windings. When capacitive DC blocking devices of No. 1 and 2 transformers were put into action, DC current of common winding was zero. But due to features of autotransformer, flow path of DC current in series windings was not cut off, and DC current could form electrical connection with 330kV bus from 750kV bus through series windings of two main transformers and then form a loop with connected 330kV substation [6-7].

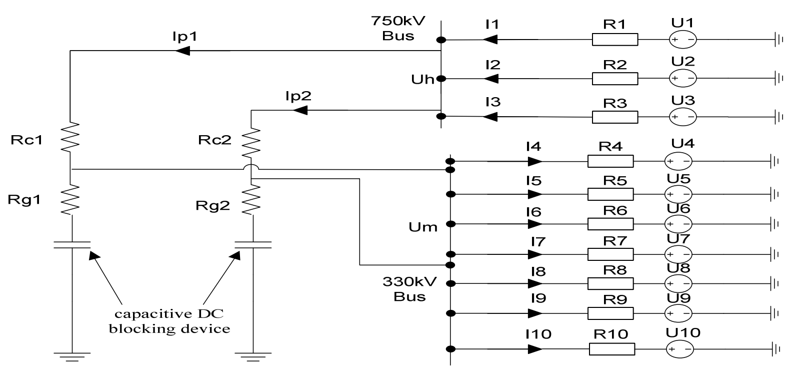

Figure 2. Computational model of DC current.

Uh and **um** are DC voltages of buses at 750kV and 330kv sides in Dunhuang substation respectively, which are solved using nodal voltage method.

$$G_L(U_h - U_m) = G_1(U_h - U_1) + G_2(U_h - U_2) + G_3(U_h - U_3) \quad (1)$$

$$G_L(U_h - U_m) = G_4(U_m - U_4) + G_5(U_h - U_5) + \cdots + G_{10}(U_h - U_{10}) \quad (2)$$

Where -is conductance of -.

$$U_h = \frac{G_1 U_{1+} G_2 U_{2+} G_3 U_3}{G_1 + G_2 + G_3}$$

$$U_m = \frac{G_5 U_5 + G_6 U_6 + \cdots + G_{10} U_{10}}{G_5 + G_6 + \cdots + G_{10}}$$

When capacitive DC blocking device is put into action at neutral point in Dunhuang substation and no DC current flows through series winding, it can be solved through formulas 1 and 2.

Therefore, the following conditions must be met in order to make DC current not flow through autotransformer winding in Dunhuang substation

$$\frac{G_1 U_{1+} G_2 U_{2+} G_3 U_3}{G_1 + G_2 + G_3} = \frac{G_5 U_5 + G_6 U_6 + \cdots + G_{10} U_{10}}{G_5 + G_6 + \cdots + G_{10}} \quad (3)$$

Ground potential of substation presents nonlinear change due to ground current at ground electrode [11], so even though condition of formula 3 is satisfied under one load condition, ground potentials can’t be maintained equal with load change, and potential difference between substations increase as ground current increases, so DC current will flow between 750kV bus and 330kV bus.

3.2. Verification of data verification

In the circuit shown in Fig. 4, 750kV bus and 330kV bus taken as nodes, DC current flowing through autotransformer winding in Dunhuang substation can be solved through KCL equation:

$$I_p = I_{p1} + I_{p2} = I_1 + I_2 + I_3 \quad (4)$$

$$I_p = I_{p1} + I_{p2} = I_4 + \cdots + I_{10} \quad (5)$$

Where - are DC currents of neutral points of 750kV and 330kV substations respectively connected to the central substation.

It can be known from formulas 4 and 5 that the current flowing through winding in Dunhuang substation is equal to sum of DC currents at neutral points of substations at 750kV bus side and also equal to the sum of those at 750kV bus side. Data are seen in Table 3, when ground currents at ground electrodes are not the same, it can be seen that sum of DC currents of neutral points in 750kV substations is largely equal to that in 330kV substations and neither are zero, and this verifies that DC current flows through autotransformer winding.

Table 3. Comparison of measured current values at neutral points of 750kV side and 330kV side.

Ground electrode Idc/A	Sum of current values at neutral points of 750kV side/A	Sum of current values at neutral points of 330kV side/A
500	-5.4	5.6
1500	-12.9	13.4
2500	-14.7	15.5
3250	-18.7	18.2
4000	-21.1	21.9
5000	-25.8	26.9

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4. Analysis of secondary waveforms of current transformers at neutral points

4.1. Current measurement of common winding

Transformers in 750kV Dunhuang substation were three-phase transformers, three-phase neutral points were led out and directly grounded, and there were two types of current transformers at neutral point of each phase as shown in Fig. 3. Current transformer models were LRBT-110 and LR-110 respectively which were used for protection and measurement respectively. Although this current transformer was also electromagnetic transformer, DC magnetic bias would generate the similar influence of transformer, but after capacitive DC blocking device was installed at transformer neutral point and put into action, DC current would not flow in common winding. Therefore, current in transformer common winding could be measured through LR-110 current transformer used for measurement [8].

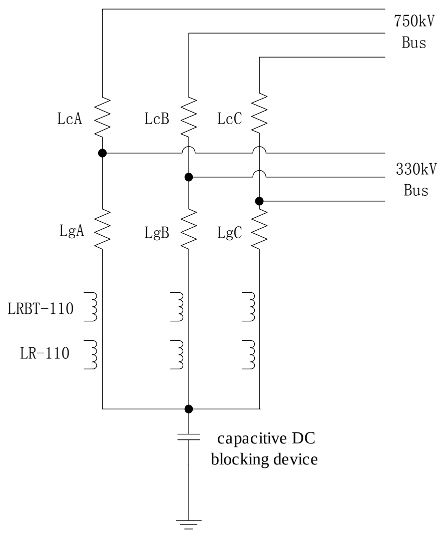
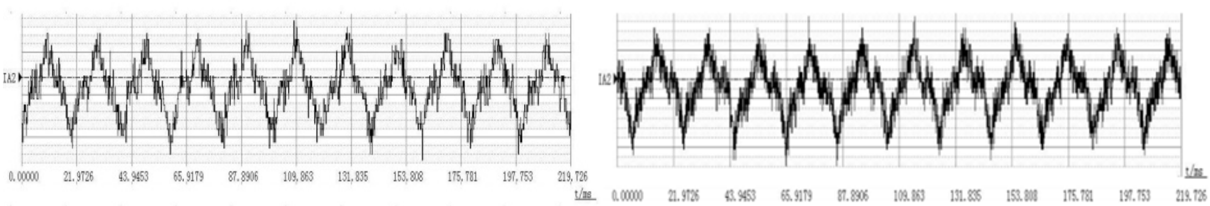
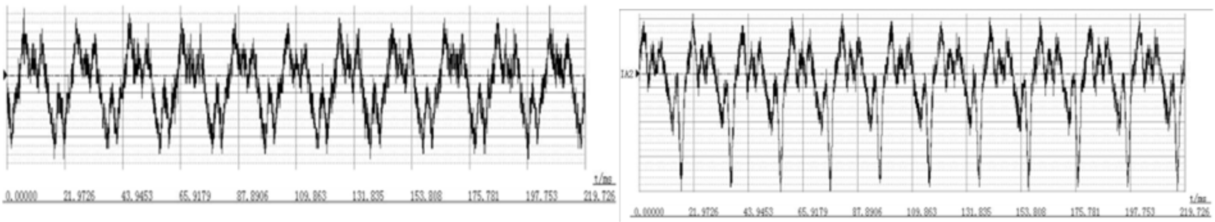


Figure 3. Current transformers at neutral points of 750kV autotransformer.

During the second DC magnetic biasing test of “Qi-Shao” DC debugging, neutral point current transformer was used for current recording of phase a transformer of No. 1 substation in different DC load stages when transformer noise and vibration went through any abnormality in Dunhuang substation. Fig. 4 showed that when current at ground electrode reached 5,000A, winding current experienced more serious distortion, sinusoidal waveform had already turned into spike pulse waveform, and DC magnetic biasing phenomenon was more serious.



(a) Idc=500A (b) Idc=1500A



(c) Idc=3250A (d) Idc=5000A

Figure 4. Secondary-side current waveforms of current transformers at neutral points in differentDC load periods.

This THD (total harmonic distortion) was computed and result was shown in Table 4. When 5,000A current was grounded at ground electrode, distortion rate of transformer magnetizing current already reached 89.28%, which verified that the transformer was still affected by DC magnetic bias when capacitive DC blocking device was put into operation at transformer neutral point.

Table 4. Distortion rates of secondary-side current waveforms of current transformers at neutral points in different DC load periods.

Ground electrode Idc/A	THDI (%)
500	12.09
1500	23.87
3250	51.17
5000	89.28

4.2. Harmonic content analysis

Harmonic analysis was conducted for currents in Fig. 4, and harmonic contents under different DC loads were shown in Table 5. It could be seen from Table 5 that change sensitivity of secondary harmonic content was superior to those of other harmonic contents. Therefore, operation and maintenance department could indirectly judge severity of DC magnetic bias of transformers only needing to monitor secondary harmonic contents in CT secondary current at neutral points.

Table 5. Harmonic contents in CT secondary-side currents at neutral points in different DC load periods.

Ground electrode Idc/A	Secondary harmonic/A	Third harmonic/A	Fourth harmonic/A	Fifth harmonic/A
500	0.20	0.21	0.06	0.01
1500	0.41	0.4195	0.14	0.02
2500	0.70	0.78	0.59	0.05
3250	0.89	0.83	0.50	0.05
4000	1.18	1.16	0.84	0.44
5000	1.62	1.48	1.37	0.57

5. Conclusion

Through an analysis of DC magnetic bias data in Dunhuang substation during Qi-Shao DC debugging period, it’s found that transformer vibration and noise still continued to increase after capacitive DC blocking device was put into action. Based on this problem, structural features of 750kV autotransformer were combined to conduct in-depth analysis of DC current distribution in Dunhuang substation—centered local power network after capacitive DC blocking device was put into action at neutral point. Concrete conclusions were as follows:

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After capacitive DC blocking device was put into action at neutral point in 750kV autotransformer, DC current might flow in transformer series winding, which resulted in continuous increase of transformer vibration and noise. Comprehensive analysis was needed after test of DC current distribution in regional power network.

After capacitive DC blocking device was put into action at neutral point in 750kV autotransformer, secondary-side current waveforms in current transformer at neutral point in single-phase transformer could be monitored. Whether the transformer went through DC magnetic bias could be judged through current waveform distortion. Meanwhile, severity of DC magnetic bias could be indirectly judged according to change of secondary harmonic contents in this current so as to provide decision-making basis for operation and maintenance personnel.

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