Vibration and noise suppression method of transformer

XC Yu, DP Zou, MZ Fan, X Dong and F Du
State Grid Liaoning Electric Power Co., Ltd. Dandong Power Supply Company, Dandong, 118000, China
*corresponding author’s email: haixiy@36haojie.com

Abstract. Aiming at the problem of noise and vibration of distribution transformer body and base connector under heavy load, the corresponding relationship between vibration and noise, load and power factor of distribution transformer is studied in this paper. In order to improve the operation reliability of distribution transformer, a noise and vibration suppression method based on load scenario optimization is proposed. From the aspects of design reliability, data detection and noise level correction, the typical relationship between the increase of noise level and DC current, noise spectrum and DC bias noise is obtained, and the DC bias limiting measures and correction suggestions are given.

Keywords. transformer; Bias and materials; Rectification measures

1. Introduction
When DC current flows into AC transformer, it will be in abnormal working state. DC current will generate DC flux inside the transformer, and superposition with AC flux will change the magnetic density of AC equipment core, cause excitation current distortion, increase harmonic component of AC system, reduce effective transmission capacity of transformer, and even lead to protection system Maloperation is a threat to the safe and stable operation of power grid. In China's power grid construction, high-voltage transmission lines are mainly East-West oriented, with long-distance, large capacity and other transmission characteristics. However, the East-West transmission lines are vulnerable to the influence of magnetic storms, resulting in DC bias; in addition, the bipolar unbalanced operation and monopole earth return mode in DC transmission projects will also be affected The DC current flows into the transformer winding with neutral grounding, and DC magnetic bias occurs. Therefore, large power transformers are often affected by geomagnetic current, DC transmission monopole operation, resulting in DC bias, threatening the safe and stable operation of the power grid.

The abnormal vibration and noise of transformer caused by DC bias is one of the main problems that people pay attention to. The research work of transformer vibration and noise monitoring in foreign countries is earlier than that in China. Since the 1930s, the United States, Finland, Canada, Japan and other countries have carried out research on the aggravation of DC magnetic bias noise and its impact on power grid operation. Since 2001, domestic colleges and universities, power production and design units have done a lot of research work combined with the magnetic bias saturation of Wunan and Lingao nuclear power stations in Jiangsu Province. Among them, the noise of main transformer in Wunan substation has increased by 21 dB due to the influence of DC magnetic bias, and the obvious odd harmonic appears in the noise spectrum [3-4]. Referring to the previous research, this paper analyzes the abnormal noise phenomenon of No.2 and No.3 transformers in a new substation, expounds in detail the relationship between the increase of noise sound level and DC current, noise spectrum and typical spectrum of DC
magnetic bias noise, and puts forward rectification suggestions, which can provide reference for the follow-up research work.

2. Analysis of vibration and noise data of transformer

The vibration noise of DC bias mainly comes from the vibration of iron core and winding, and the vibration signal is transmitted to the shell in different ways. The iron core consists of the magnetostrictive effect of silicon steel sheet is caused. Vibration is transmitted to the oil tank mainly through two ways, one is transmitted to the oil tank through the pad foot, the other is transmitted to the oil tank through insulating oil. The vibration of winding is caused by electromagnetic force, which is mainly transmitted to the oil tank through insulating oil; the vibration of cooling devices such as fans can also be transmitted to the oil tank of transformer through solid way.

When the transformer works normally, the excitation current is symmetrical in the positive and negative half cycle, and the AC excitation flux is symmetrical in the positive and negative half cycle, so the magnetostrictive displacement is also symmetrical in a period of flux change. When DC passes through AC transformer, the changes of internal excitation current and excitation flux under over excitation state and DC bias are shown in Fig.1.

In the case of DC bias, due to the superposition effect, the corresponding excitation current presents the shape of positive and negative half wave asymmetry. The half cycle which is consistent with the magnetic bias direction increases greatly, while the other half cycle decreases, resulting in half wave saturation, as shown in Fig. 2 (compared with Fig. 1). The results show that the magnetostrictive displacement is positively correlated with the square of the magnetic flux [7], and the magnetic flux is positively correlated with the exciting current. Therefore, the magnetostrictive displacement of the iron core will appear asymmetry in a cycle, including not only even harmonic component but also odd harmonic component.

When the transformer works normally, the winding vibration is basically positively correlated with the square of the current. Therefore, the winding vibration is mainly composed of 100 Hz fundamental frequency and high-order harmonics with integral times of the fundamental frequency. Under DC bias, due to the distortion of excitation current, a large number of odd and even harmonics will appear in the winding vibration.

To sum up, the vibration of the transformer will become more complex and a series of high-order harmonics will appear in the case of DC bias.
The noise level increases obviously with the increase of DC magnetic bias, and the noise level is related to the ratio of DC magnetic bias current to no-load current.

3. Analysis of multi scene operation characteristics of transformer and its corresponding relationship with vibration and noise

In addition to the project cost, foreign projects should also take No.2 and No.3 main transformers of a new substation as an example, the abnormal noise situation is analyzed. The transformer model is sfz10 180000 / 220; the rated voltage is 230 ± 8 × 1.25% 121 / 11 kV; the rated capacity is 180 / 180 / 90 MVA; the connection group is yyn0d11; the main tap impedance is 14% / 48% / 33%. No.2 main transformer is grounded and No.3 main transformer is not grounded.

After putting into operation, the noise of No.2 main transformer is obviously higher than that of No.3 main transformer. After field investigation and analysis, the No.3 main transformer is grounded after the No.2 main transformer is out of operation. The results show that the noise of No.3 main transformer becomes larger, which is the same as that of No.2 main transformer when grounding.

The factory test noise of No.2 and No.3 transformers are 58.2 dB and 59.7 dB respectively. The noise of No.3 main transformer is 68 dB, and the sound absorption coefficient of transformer room is 0.05. The increment of sound pressure level in decibels.

\[
d_{\text{build-up}} = 10\log \left[ 1 + \frac{4(1-\alpha)A_n}{A_r} \right]
\]

Where: \(d_{\text{build-up}}\) is the increase value of noise level; \(\alpha\) is the correction coefficient; \(A_r\) is the measured sound pressure; \(A_n\) is the reference sound pressure.

The calculated noise level increases by 10.4 dB. Therefore, the noise level of the transformer without grounding is 68.6 dB.

The two transformers in the station are all high impedance transformers with built-in reactor structure. The transformer manufacturer has adopted the built-in reactor structure in dozens of high impedance transformers in 19 substations. The field operation is good and the structure is mature and reliable, which can meet the requirements of field operation. It can be seen from the correction results in Section 2.2 that the operating noise of No.3 main transformer without grounding meets the requirements of the technical agreement less than 70 dB.

The noise increase of No.3 main transformer occurs when the neutral point is changed from ungrounded to grounded, which can eliminate the noise increase caused by the transformer itself. The noise amplitude frequency analysis of No.3 main transformer spectrum analyzer is shown in figure 3.

After the station is directly grounded through the neutral point of No.3 main transformer, it provides a way for the DC current in the system to flow into the earth's crust. The DC value of the neutral point on the high voltage side is 1.10 a, and the DC current of each phase is 0.41 a. The factory value of no-load current is 0.05%, and the rated current and no-load excitation current of high-voltage side are 472.4 A and 0.24 a respectively. The ratio of magnetic bias DC to no-load current is 1.5. Combined with the relationship.
between the increase of noise level and the DC current, it can be seen that the noise upgrade increases by about 13 dB.

The actual measurement results show that the noise of No.3 main transformer is 68 dB when the neutral point is not grounded. After the neutral point is grounded, the noise increases to 85 dB, and the actual increase is 17 dB. The theoretical calculation value of noise level is basically consistent with the actual measurement.

![Figure 3](image)

Figure 3. noise amplitude frequency analysis of No.3 main transformer spectrum analyzer

The noise of main transformer under no-load state is mainly 100 Hz and its multiple frequency, and the frequency with the highest amplitude is 300 Hz.

The noise spectrum of No.3 main transformer is composed of even and odd harmonics, mainly even order. After DC bias is injected into the transformer, its excitation current is saturated, so that the harmonic component of vibration contains odd harmonic component.

Using MATLAB simulation analysis, the noise spectrum of no-load test of No.3 main transformer is shown in Fig.4 (a), and the noise spectrum analysis of No.3 main transformer under DC bias is shown in Fig.4 (b)
The suppression of DC bias is generally realized by adding a suppression device between the neutral point and the ground. The suppression device can add a DC generator to inject a certain amount of reverse DC current into the substation grounding grid to reduce its potential, and carry out reverse compensation for the grounding DC to reduce the DC current flowing through the neutral point and restrain the influence of DC bias. Relay protection and insulation level have no influence. The current limiting resistor or isolating capacitor can also be used in the suppression device. However, in this case, the DC bias is slightly greater than 1 A, and low resistance or DC generator is generally used to suppress it. However, considering that the installation of small resistance will have a certain impact on the system structure, DC generator is used to suppress DC.

There are two main transmission paths of core vibration: one is that the iron core transmits the vibration to the bottom of the oil tank through the support bolt which is rigidly connected with the bottom of the oil tank, thus causing the bottom-up vibration of the oil tank. The vibration transmission mode is "solid-solid" transmission, which has the unidirectional attenuation characteristics of vibration when transmitted by a single solid path; the other is that the iron core passes through insulation. The vibration is transmitted to the surface of the oil tank, thus causing the overall vibration of the oil tank. The vibration transmission mode is "solid liquid solid". On the solid-liquid coupling interface, the vibration of the iron core causes the movement of the insulating oil, and the movement of the insulating oil causes the vibration of the oil tank. In addition, due to the difference of material structure, material and distance, the vibration frequencies of the two paths have different amplitude attenuation, resonance and coupling in the process of transmission, thus forming a vibration distribution characteristic completely different from the core vibration characteristics when reaching the tank shell, which is from the core to the oil tank. It is the result of the interaction of natural attenuation mechanism and coupling attenuation mechanism.

In addition, the vibration spectrum of transformer core, oil tank vibration and near-field noise measurement points under different voltages are analyzed, and the peak frequencies of transformer core, tank vibration and near-field noise are calculated. It can be seen that the peak frequencies of core and tank vibration and near-field noise are basically the same under different no-load voltages, which further illustrates the significant correlation between core and tank vibration and near-field noise. Specifically, the peak frequency is mainly concentrated in 100Hz, 200Hz and 300Hz, which is due to the frequency of the external power frequency magnetic field of 50 Hz, the nonlinearity of the core hysteresis expansion, and the different length of the magnetic flux path along the inner and outer frames of the core, resulting in the waveform of the actual core magnetic flux density is not a standard sine wave. Therefore, in addition to 100Hz fundamental frequency, 200Hz, 300Hz and other harmonics are also obvious. Results shows the frequency spectrum characteristics of transformer core and tank vibration and near-field noise under 100% no-load voltage.

Figure 4. matlab simulation analysis image
4. In conclusion

Starting from the vibration mechanism of transformer DC bias, the noise characteristics of transformer magnetic bias vibration are analyzed, and the abnormal phenomenon of vibration and noise of main transformer in newly put into operation substation is elaborated in detail. The vibration and noise of transformer is mainly determined by the vibration of iron core and winding, which takes twice the power frequency as the fundamental frequency (100 Hz) and contains the higher harmonic whose frequency is integral times. Under the action of DC bias, the excitation current is distorted, and the corresponding noise signal also appears a lot of odd order noise. When the abnormal noise of main transformer is caused by DC magnetic bias, injecting reverse DC into neutral point is an effective measure to limit DC bias.

5. References

[1] Ahmed SA, Awad T and Magdy MAS 2015 Optimal ESS Allocation for Load Management Application[J] IEEE Transactions on Power systems 30(1) pp 327-336
[2] Saejiam G 2012 Alleviation of power systems with and farm by SMES with optimal coil size[J] IEEE Trans on Applied Superconductivity 6(22) PP 2
[3] Sutanto D 1999 Power management solutions for energy management, power quality and environment using battery energy storage systems[C] IEEE 1999 International Conference on Power Electronics and Drive Systems Hong Kong I pp 523-528
[4] Jeroen T, Frederik G and Daah S 2013 Multiobjective battery storage to improve PV integration in residential distribution grids[J] IEEE Transactions on Sustainable Energy 4(1) pp 182-192
[5] Geng YL, Ming Z and Bo L 2006 An Alternative Approach for Coordinating Dispatching Day-Ahead and Real-time Energy Markets[J] Power Systems Conference and Exposition pp 1162-1167
[6] Mahamadou AT, Mamadou BC and Brayima DY 2013 Use of Ultracapacitors and Batteries for Efficient Energy Management in Wind-Diesel Hybrid System[J] IEEE Transactions on Sustainable energy 4(2) pp 414-424
[7] Pedro F and Zita V 2011 Demand Response Management in Power Systems Usinga Particle Swarm Optimization Approach[J] IEEE Intelligent System 90 pp 1