How to Measure and Analyze the Vibration and Noise of 500kV Power Transformer Caused by DC Magnetic Bias

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Abstract: The on-line synchronous monitoring scheme on 500kV single-phase power transformer is designed in the paper. With the application of vibration and noise sensor, data acquisition and analysis system, single-phase power transformer in 500kV substation is monitored real-time under the DC magnetic bias condition. The vibration and noise time-domain waveform data before and after DC bias are recorded, and spectrum range of vibration and noise signal are analyzed. Test results show that vibration and noise amplitude of power transformer under the influence of DC bias increase obviously, and large quantities of high harmonic appear, which is not helpful for normal operation of transformer.

Key words: Transformer vibration, noise, DC magnetic bias, on-line monitoring, spectrum

1. Introduction

With the formation of AC-DC hybrid transmission mode, mutual interference of AC and DC system also comes. When the DC line adopts mono-pole operation mode, the DC current, which flows into the ground through grounding electrode, will have an influence on electric equipment in the AC electric system. Under the mono-pole operation mode, some transformers vibrates more violently, and the noise becomes louder. The comparison between noise and debug load indicates that there is close link between them. Large quantities of similar test data prove that DC magnetic bias is the main cause for vibration and noise intensification.

When DC bias occurs, internal leakage flux greatly increases in terms of amplitude, and plenty of high harmonics also appear. Hence, the vibration of windings and silicon steel sheets intensifies. The vibration transmits to box surface through insulation oil and iron foot pad. The amplitude and harmonic increase as well.

The test object is a single-phase power transformer in the 500kV substation. The vibration and noise sensor is adopted to synchronously extract the waveform of noise and vibration signal with or without DC bias at high sampling frequency. The relation curve between vibration, noise and DC bias is presented. Also, one method of judging the influence of DC bias on noise and vibration is proposed.

2. On-site Measurement and Results

2.1 Test device and measuring scheme

There is a close link between vibration of transformer surface and compress, shift and deformation of transformer winding and iron core. Therefore, measurement of power transformer vibration can reflect the condition of winding and iron core vibration, and monitor the transformer through measuring the transient sound pressure on the transformer surface. Meanwhile, because this monitoring system is not connected to the whole electric system, it will not have an impact on the normal operation of electric system.

The vibration and noise on-line monitoring device can be divided into two parts: signal acquisition part and background processing part. The front machine is composed of vibrating sensor and noise sensor. First of all, three monitoring directions should be determined; secondly, the position where measuring point is can fully reflect vibration condition of transformer, and does not weaken due to the limitation of box surface structure; finally, the position needs to be easy to locate and install the sensor to ensure high repeatability and precision of the test. Three vibration points to measure are determined shown in Fig.1. The noise sensor is placed at the place 1.5m away from Point 1; digital signals formed by collected real-time signal through data acquisition and filtering are displayed, stored and analyzed by background computer.

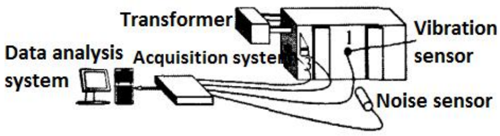


Fig.1 Monitoring device of transformer vibration and noise

2.2 Measuring results of vibration and noise signal

In the process of debugging, sampling frequency is set high to reflect vibration and noise spectrum as precisely as possible. The measuring unit of vibration is m/s^2. The direction of installation plane pointing to the sensor is positive direction; the unit of noise transient sound pressure is Pa. The monitored waveform of three vibration measuring points and one noise point before and after the DC bias is shown in Fig.2-5.

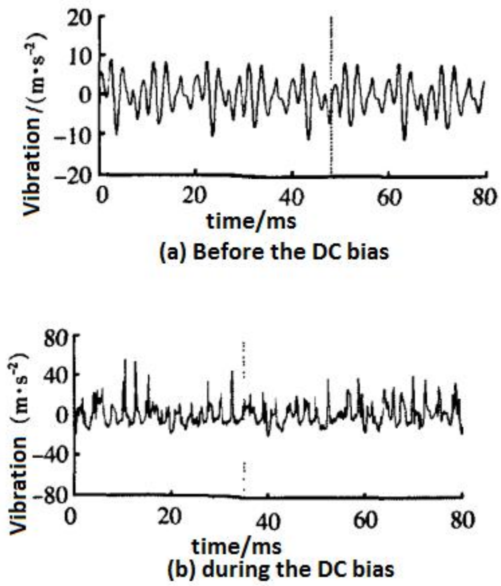


Fig.2 Time-domain waveform of Point 1 with/without DC bias

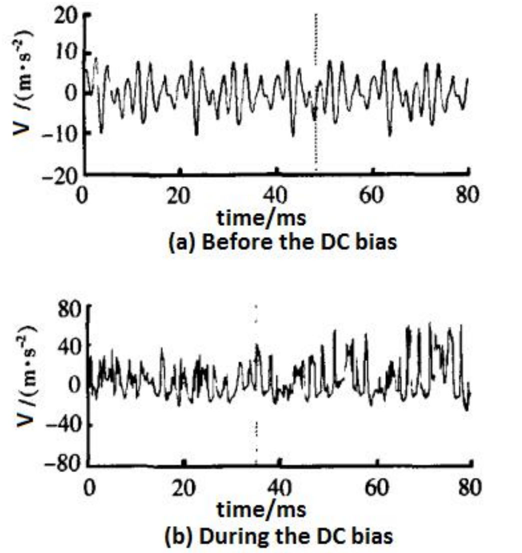


Fig.3 Time-domain waveform of Point 2 with/without DC bias

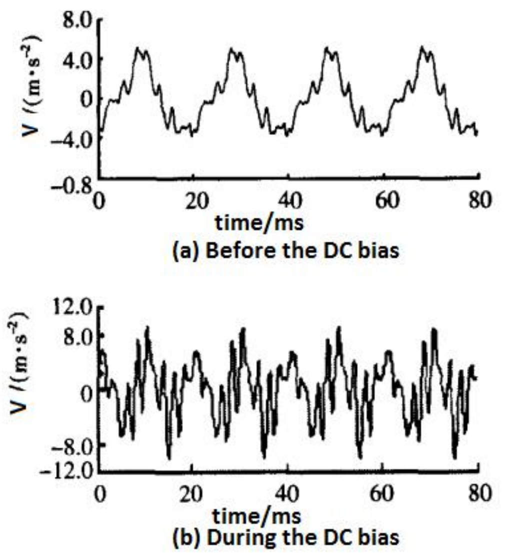
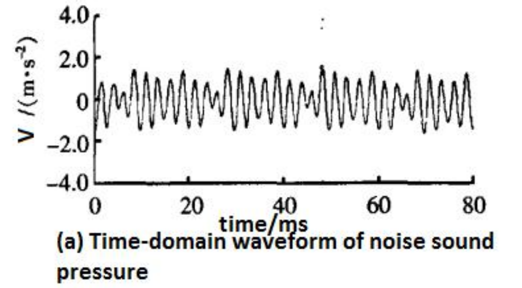


Fig.4 Time-domain waveform of Point 3 with/without DC bias



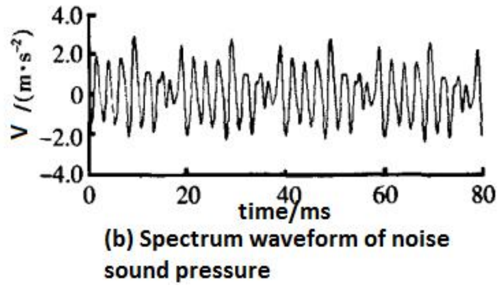


Fig.5 Time-domain waveform of noise transient sound pressure with/without DC bias

3. Analysis of Test Results

3.1 Analysis of different measuring points' waveform

Although waveform is different from spectrum, variation trend of time-domain waveform is similar to that of frequency spectrum of three measuring points before and after DC bias.

When DC magnetic bias does not appear, time-domain waveform of the vibration of oil tank's inner side is clear and stable; the waveform also manifests obvious periodicity and is relatively regular; its symmetry is good. While DC magnetic bias comes out, the waveform is out of order, and upper waveform is not obviously symmetrical to lower waveform. The vibration peak value of Point 1 increases from 1g to 4g. Under the influence of transformer structure, vibration amplitude of opposite direction increases from 1g to 2g . The peak value of Point 2 increases from 1g to 6g, with an increase of 5g; valley value increases from 1g to 2g. As for Point 3, the variation is small, from $4m/s^2$ to $10m/s^2$ for peak and valley value. The noise waveform varies slightly, from 1.5Pa to 3Pa.

Analysis of frequency spectrum shows

that high harmonic appears. Main frequency still dominates when there is no DC magnetic bias.

3.2 Variation of vibration and noise amplitude according to magnetic bias current

The neutral point current is monitored by No.3 main transformer, which is shown in Fig.6. The obvious DC magnetic bias starts to appear at 14:40. The system monitors the variation of vibration and noise through the whole process of DC bias generation.

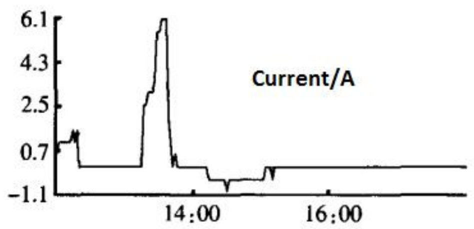


Fig.6 Neutral point DC

The noise and vibration waveform is shown in Fig.7. Based on monitoring results, there is clear correlation between DC bias and vibration and noise of transformer body .

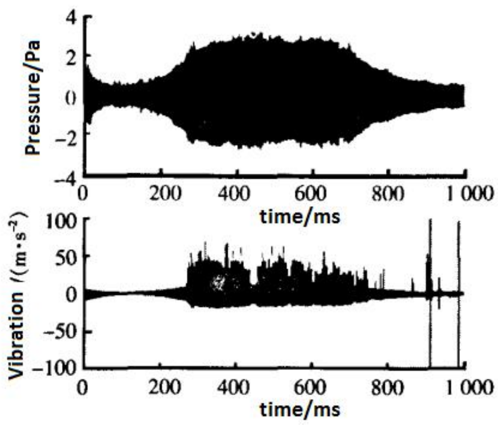


Fig.7 Synchronous waveform of vibration and noise

The amplitude of vibration and noise time-domain waveform of Point 1 recorded by monitoring system is compared with neutral point DC value recorded in the main control room of substation. The correlation between vibration amplitude and DC bias current is reflected in Fig.8. As the DC magnetic bias flowing into AC transformer neutral point increases, the vibration of AC transformer is inclined to increase in a linear manner. Every 1A increase in DC current will cause the vibration amplitude to increase by 1.1g or so; when DC magnetic bias is 0, vibration amplitude is about 2g; similar monitoring indicates that every 1A increase in DC current results in noise sound pressure increasing by about 0.9Pa.

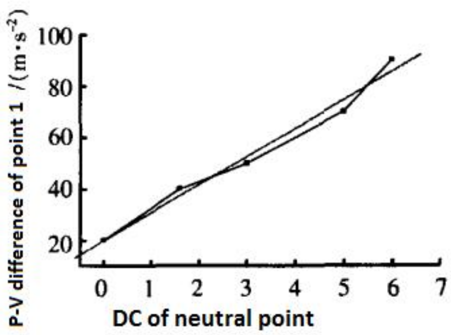
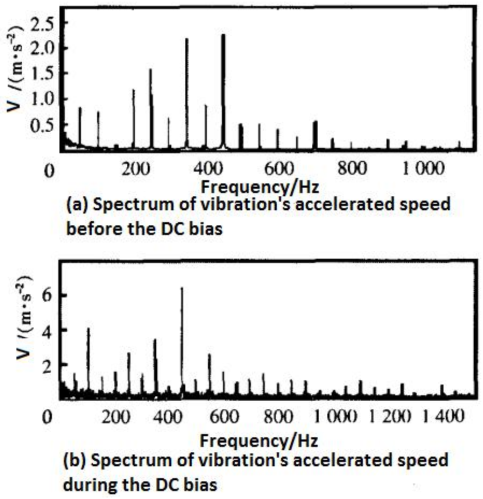


Fig.8 Curve that shows the influence of DC bias current on transformer vibration

3.3 Variation of vibration wave spectrum

The spectrum of vibration's accelerated speed in the process of the DC bias is shown in Fig.9. According to Fig.9, when there is no DC magnetic bias, the spectrum of transformer oil tank's inner side vibration is basically concentrated within 1kHz, especially 100-500Hz. However, high frequency component above 1kHz can be neglected. When DC magnetic bias appears, medium-high frequency component increase substantially. The 500-1000Hz harmonic increases in a even and stable pattern. Even corresponding high harmonic appears between 1kHz and 1.4kHz. That reflects that the vibration of internal winding and iron core changes obviously.



(a) Spectrum of vibration's accelerated speed before the DC bias

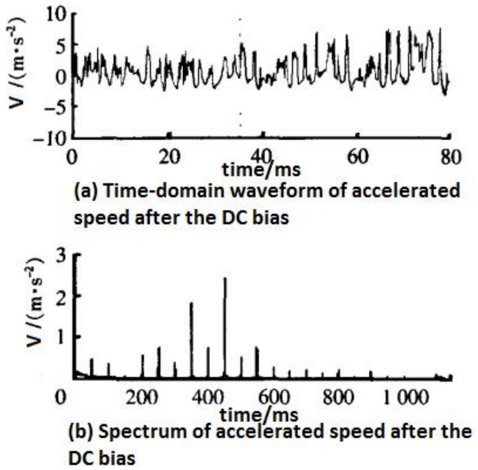
(b) Spectrum of vibration's accelerated speed during the DC bias

Fig.9 Spectrum of Point 1 before and after the DC bias

3.4 Analysis of possible influence of vibration on the transformer operation

The over-high DC magnetic bias intensifies the saturation of transformer iron core. Exciting current distorts and the magnetostriction of silicon steel enhances. Moreover, saturated iron core turns into higher magneto-resistive path. The leakage magnetic flux increases, causing intensified winding vibration and louder noise.

The violent vibration will have an impact on mechanical strength of transformer structure during the process of DC magnetic bias, even loosen fixed parts. Hence, it is necessary to compare vibration waveform and spectrum of transformer before and after the occurrence of DC bias. The Fig.10 presents time-domain waveform and frequency spectrum of point 1 without DC magnetic bias. We can learn that the result is basically consistent with obtained one before DC bias. On the one hand, the process of DC magnetic bias has minor influence on transformer; on the other hand, it further verifies that DC magnetic indeed has the influence on power transformer vibration.



(a) Time-domain waveform of accelerated speed after the DC bias

(b) Spectrum of accelerated speed after the DC bias

Fig.10 Vibration time-domain and spectrum of Point 1 after the DC bias

3.5 A new method of judging operation condition of transformer

From varying degrees of vibration and noise, DC magnetic bias poses a great threat to safe operation of transformer. Close attention should be paid to the variation of vibration and noise of transformer to monitor whether there is something wrong with transformer. The author proposed a new method of determining the influence of DC bias on vibration and noise of power transformer: ① select measuring points; take the influence of load on vibration condition into account; record the vibration degree at different levels of load without DC bias; ② based on recorded results, to check whether straight line slope is within the reasonable range; ③ to check whether time-domain waveform is consistent with spectrum analysis before and after the DC bias. For instance, whether the amplitude varies within 20%; whether large quantities of high harmonic appear between 500Hz and 1400Hz.

If above-mentioned problems occur, there may be something wrong with transformer structure.

4. Conclusions

(1) When the transformer is in normal operation, vibration and noise waveform is clear and stable and has obvious periodicity, which provides a powerful data and long-term judgment basis for fault diagnosis and maintenance of power transformer.

(2) Before and after DC magnetic bias, time-domain waveform and spectrum of three measuring points vary similarly. Without DC magnetic bias, time-domain waveform of the vibration of oil tank's inner side is clear and stable; the waveform also manifests obvious periodicity and is relatively regular; its symmetry is good. While DC magnetic bias comes out, the waveform is out of order, and upper waveform is not obviously symmetrical to lower waveform. The peaks of vibration of three points increase obviously.

(3) In terms of amplitude, as the DC magnetic bias flowing into AC transformer neutral point increases, the vibration of AC transformer is inclined to increase in a linear manner. In addition, noise and vibration vary synchronously. The noise level also reflects operation condition of transformer.

(4) When the transformer operates normally, vibration frequency of surface in horizontal direction takes 100Hz as fundamental frequency; largest proportion is between 200Hz and 500Hz; it can be neglected above 1000Hz. When DC magnetic bias appears, high harmonic occurs between 500Hz and 1.4kHz.

(5) Owning to complex transformer structure, current monitoring work focuses on variation. Further research and discussion are needed for fault analysis and location.

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