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ANALYSIS OF AUDIBLE NOISE AND VIBRATION TO DETECT DC-BIAS IN POWER TRANSFORMERS

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DC-bias is a potential threat to the safe operation of power transformers. In this paper, field audible noise and vibration of a 220kV power transformer is measured. The noise and vibration signals are found changing simultaneously with the variation of direct current in the grounded neutral point of the power transformer. Noise and vibration characteristics in both time and frequency domain of the power transformer before and after DC-bias are analyzed. In order to enhance the precision of DC-bias detection, two features are extracted from the noise and vibration frequency spectra which are the odd-even rate of the harmonics of 50Hz and the harmonic distortion rate. Time variations of the features are compared with that of the power transformer noise and vibration. The result shows that both features when DC-bias occurs are obviously increased compared with that in normal condition, and are in good agreement with the variation of transformer noise and vibration. Therefore, it could be further applied in the DC-bias condition evaluation of power transformers.

Keywords: noise and vibration, power transformer, DC-bias, condition evaluation

1. Introduction

DC-bias is a phenomenon caused by direct current in earth flowing into the neutral point of power transformer, which leads to abnormal audible noise and vibration, local overheat and insulation damage. DC-bias occurs mostly in UHV DC power transmission project in monopole-ground operation mode [1-3]. However, this phenomenon is recently also observed in urban mass transit system (UMTS) which is supplied with DC power. Generally, direct current will not flow into AC power system if the rail insulation system of UMTS is properly constructed. Nevertheless, because of the discrepancy in soil component, construction technique and the current conducting ability of underground pipe network, there is occasionally still some stray current flowing into AC power system, consequently leading to DC-bias in power transformers [4].

As an electric technique to detect DC-bias problem, hall sensor installed on the ground bus at the neutral point of power transformer is most used on site to measure the direct current. In order to install the hall sensor, the neutral-point disconnector has to be disconnected first for safety consideration, which takes much operation time and has the risk of electric shock. Audible noise and vibration are important physical quantities to diagnose defects of power apparatus. Compared with electrical quantities, noise and vibration measurement based technique needs not to have electrical connection with power transformer. Hitherto, many efforts have been devoted to noise and vibration test of DC-bias transformers and measures to control the direct current flowing into it [5-9]. In these researches, only spectral changes of transformer noise and vibration before and after DC-bias are analyzed. As noise and vibration variation is related with that of the direct current in the neutral point of transformer, some features could be extracted from these signals to diagnose DC-bias problem, which will be more efficient and reliable compared with amplitude and spectrum of noise and vibration signals.

In order to diagnose transformer DC-bias with noise and vibration, this paper tests on-site noise and vibration signals of a 220kV power transformer near the railway line of UMTS. Spectral variations of noise and vibration are compared before and after the occurrence of DC-bias. Two principle features are obtained and proved to be reliable for DC-bias diagnosis.

2. Noise and vibration with respect to DC-bias

2.1 Generation of DC-bias by UMTS

Theoretically, the steel rail of UMTS is insulated with the ground. All traction current flows along the rail and returns to the traction substation. However, there is actually some stray current dissipated into the ground because of the voltage drop along the rail. Part of the stay current flows into the neutral point of one power transformer T_1. After a long transmission process in the power transmission lines, it finally flows out of another transformer T_2, as shown in Fig. 1.

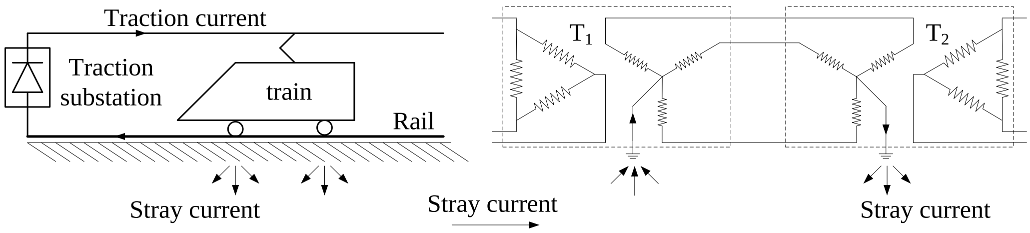


Figure 1: Schematic diagram of the stray current transmission process.

In normal condition, the magnetic flux $\varphi(t)$ of transformer core is not saturated and changes in sine waveform with the applied voltage. The magnetizing current $i(t)$ is also in sine wave form and has small amplitude, as shown in Fig. 2. The whole waveform of magnetic flux shifts away when DC-bias occurs. Magnetic flux in accordance with the shift direction increases to a large degree and that in the opposite direction decreases, which leads to half-saturation magnetization [10-11]. As magnetizing current varies with the magnetic flux in the same manner, serious distortion can be observed in its waveform, which becomes unsymmetrical in appearance. This asymmetry will get worse as direct current flowing into transformer increases. Consequently, abnormal audible noise and vibration are generated from the transformer.

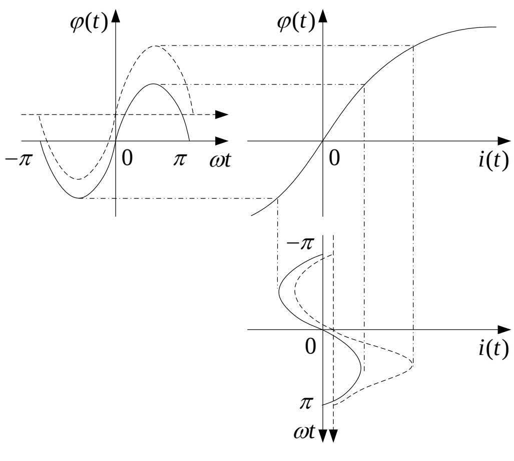


Figure 2: Schematic diagram of DC-bias.

Field tested time varying direct current, vibration acceleration and A-weighted sound pressure level (SPL) in 24h are shown in Fig. 3. The maximum values of the direct current, vibration acceleration and A-weighted SPL are 28.2A, 12.0m/s^2 and 85.4 dB(A), respectively. The variation processes of these three parameters are found exactly corresponding to the operation time schedule of the UMTS. When the UMTS is out of operation, the direct current is nearly zero, the acceleration and the SPL decrease to normal level. The changing process of direct current is in good agreement with that of the transformer acceleration and A-weighted SPL.

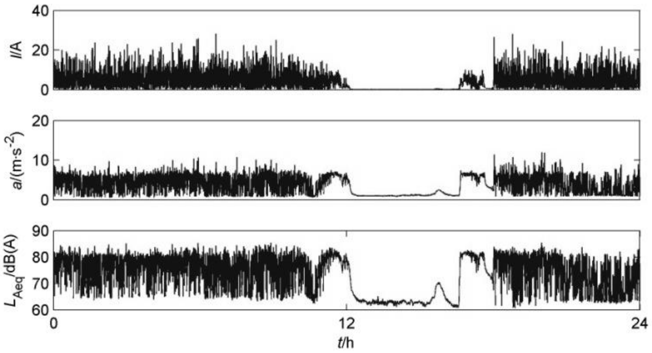


Figure 3: Transformer direct current, acceleration and SPL versus time.

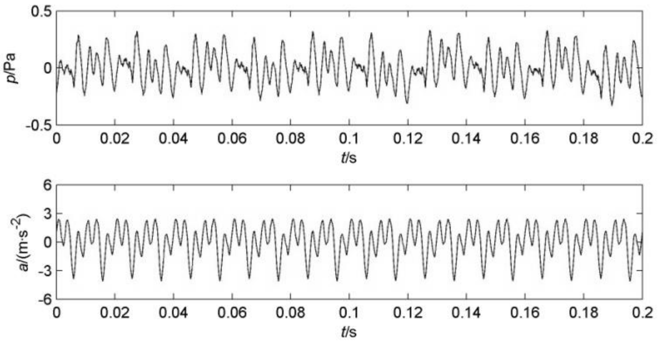


Figure 4: Time-domain waveforms of normal transformer noise and vibration.

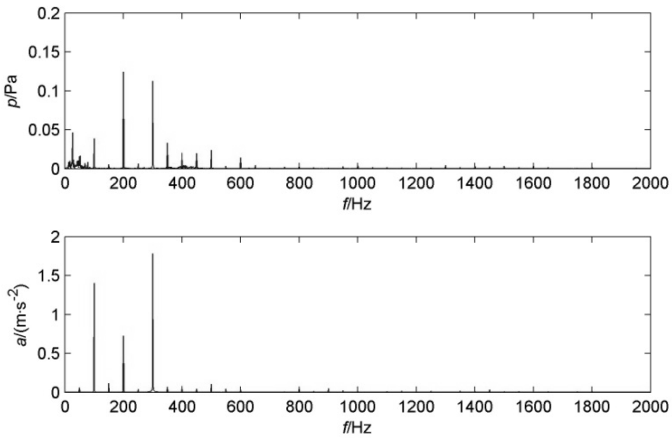


Figure 5: Spectra of normal transformer noise and vibration.

2.2 Normal noise and vibration of transformer

Noise and vibration of a 220 kV power transformer on-site are measured with B&K 4189-type microphone and 4534-type acceleration sensor, respectively. B&K 3053-type sampling module with 12 channels is used to record the noise and vibration signals with the sampling frequency of 65536Hz. Time-domain noise and vibration waveforms of the transformer are shown in Fig. 4. Cyclic waveforms can be observed. The maximum amplitudes of the sound pressure and acceleration are 0.32 Pa and 4.0 m/s^2, respectively. The A-weighted sound pressure level is 68.2 dB(A). Spectral distributions corresponding to Fig. 4 are shown in Fig. 5. It can be seen from the transformer noise spectrum that the noise frequency is mainly in the range of 600 Hz, in which 200 Hz and 300 Hz frequencies are the most prominent components. The noise amplitude of 200 Hz is 0.12 Pa. Compared with noise test, vibration measurement is less influenced by the surroundings, fewer medium and high frequency components and simpler waveform can be observed. The spectral range of vibration is mainly below 300 Hz. 100 Hz, 200 Hz and 300 Hz are the dominant frequencies. The vibration amplitude at 300 Hz is 1.8 m/s^2.

2.3 Transformer noise and vibration after DC-bias

When DC-bias happens, the direct current flowing into power transformer is time varying. An assumption can be made that noise and vibration signals is steady in a short time such as 0.2 s. Time- and frequency-domain noise and vibration signals of the transformer operating in DC-bias condition are shown in Fig. 6 and Fig. 7, respectively. The time-domain amplitudes of noise and vibration have increased several times than that in normal condition. In addition, the waveform gets more complex in appearance. The maximum sound pressure increases to 0.94 Pa and the A-weighted sound pressure level increases to 80.4 dB(A) which is 12.2 dB(A) higher than that in normal condition. The acceleration amplitude in time-domain is up to 9.4 m/s^2, which is 2.3 times larger than that in normal level. Fig. 7 gives the corresponding spectral distributions within 2 kHz of the signals in Fig. 6. Many additional harmonic components at integral multiple frequencies of 50 Hz are found in both noise and vibration spectra. In the noise spectrum, 300 Hz becomes the dominant component over 200 Hz. In the vibration spectrum, frequencies above 300 Hz are high in amplitude, in which odd multiple frequencies of 50 Hz have sharp increase. Moreover, the 500 Hz component as a new generated frequency has the highest amplitude of 3.0 m/s^2. It can be observed that DC-bias has a great influence on transformer noise and vibration.

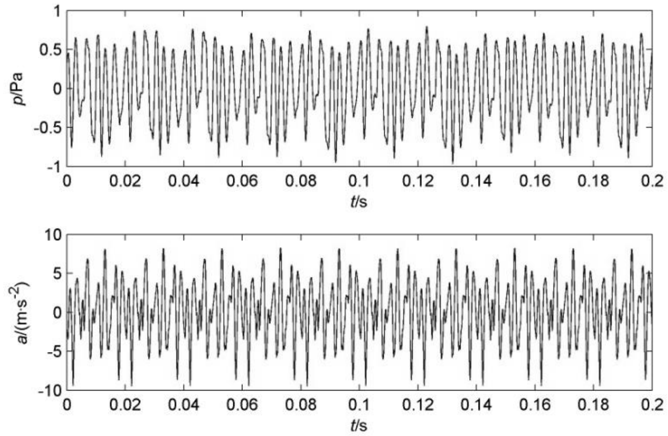


Figure 6: Time-domain waveforms of DC-bias transformer noise and vibration.

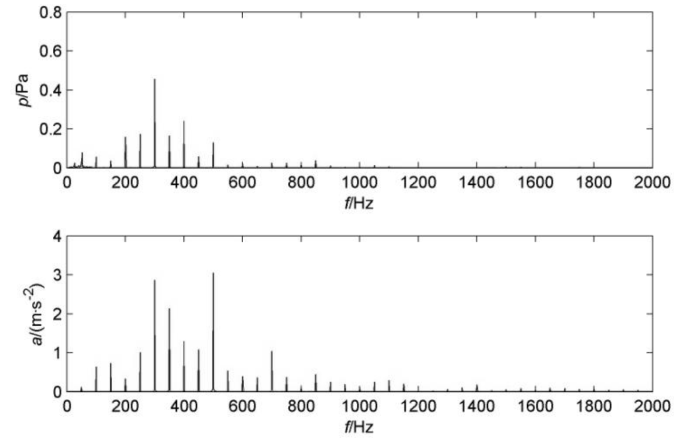


Figure 7: Spectra of DC-bias transformer noise and vibration.

3. DC-bias noise and vibration features

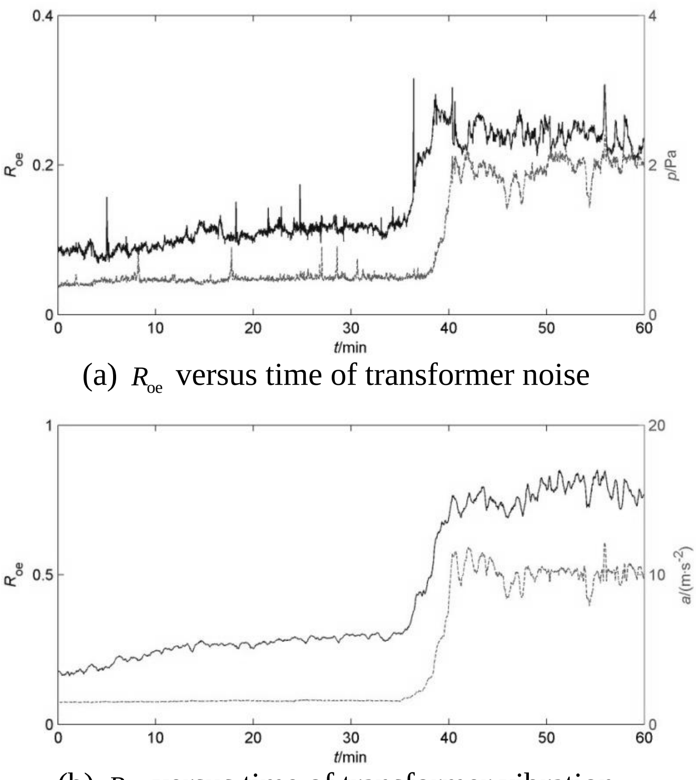
Waveform comparison in time-domain of the transformer noise and vibration before and after DC-bias shows that the amplitude of noise and vibration signals increases largely when DC-bias occurs. It seems that signal amplitude could be used as a feature to diagnose DC-bias. However, amplitudes of noise and vibration signals are also closely related with load currents of power transformers, which will much possibly lead to diagnosis failure especially when the direct current is in a low level. Compared with waveform amplitude, many features could be extracted form spectral distribution of noise and vibration signals. It can be found that the content of odd multiple frequencies of 50Hz in the transformer noise and vibration spectra has large discrepancy before and after DC-bias. Moreover, the waveform distortion is also obvious in appearance, which could be used as another feature.

3.1 Odd-even rate of harmonics

Spectra of transformer noise and vibration are basically in the range of 2 kHz. The first DC-bias feature is called odd-even rate of harmonics. It means the amplitude rate of odd harmonics to even harmonics of 50Hz within 2 kHz, which is given in Eq. (1).

$$R_{\mathrm{oe}} = \sqrt{\sum_{i=1}^{N/2} A_{2i-1}^2} \Bigg/ \sqrt{\sum_{i=1}^{N/2} A_{2i}^2} \tag{1}$$

where A_{2i} is the amplitude of even harmonics, A_{2i-1} is the amplitude of odd harmonics, N is the number of harmonics at multiple 50 Hz.



(a) R_{oe} versus time of transformer noise

(b) R_{oe} versus time of transformer vibration

Figure 8: Time variation comparison of R_{oe} feature with noise and vibration.

Field-test transformer noise and vibration signals in 1h are used to calculate the R_{oe} feature. The time variation comparison of R_{oe} feature with sound pressure and acceleration for transformer noise and vibration is given in Fig. 8. In the figure, solid line means the feature, and dashed line means sound pressure and acceleration. In the first 30min the direct current flowing into the transformer is close to zero, DC-bias is not happened in this duration. Correspondingly, the R_{oe} features of transformer noise and vibration keep in low level with small variation. During the time between 30min to 40min, both the noise (vibration) and the feature increase rapidly, while the R_{oe} feature seams much more sensitive for it rises up several minutes in advance. Good agreement is found between the variation process of the feature and noise (vibration). The curve of vibration feature is also found much smoother than that of noise feature, which attributes to that vibration is less influenced by the surroundings.

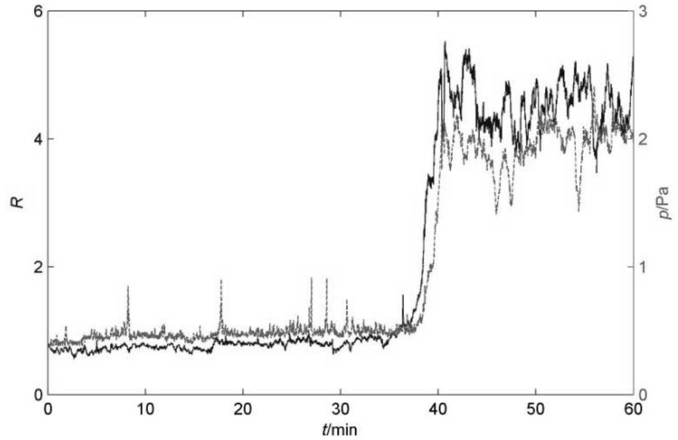
3.2 Harmonic distortion rate

The other feature used to diagnose transformer DC-bias is the harmonic distortion rate of noise and vibration signals, as shown in Eq. (2).

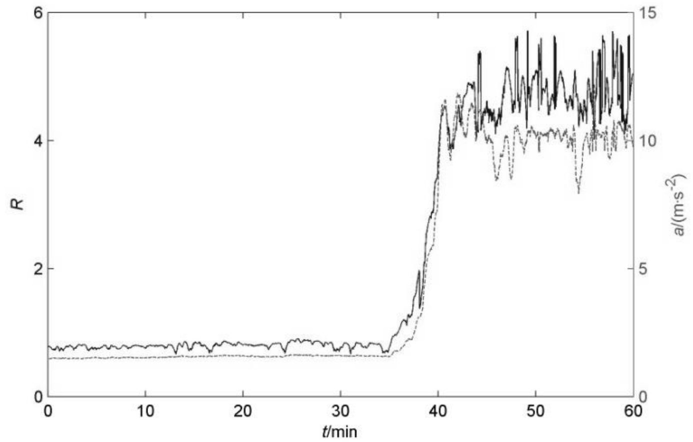
$$R = \frac{1}{A_j}\sqrt{\sum_{i \neq j} A_i^2} \tag{2}$$

where A_i is the amplitude of the ith harmonic of 50Hz, A_j is the 100 Hz amplitude of transformer noise and vibration.

The time variation comparison of R feature with noise and vibration is given in Fig. 9, in which the solid line means R feature and the dashed line means sound pressure and acceleration. The feature variation is found to be in good agreement with that of the sound pressure and acceleration. When DC-bias does not happen, the feature keeps steady, obvious change is not found. This situation changes rapidly when the UMTS is in operation, fluctuant process in found in the last 20 min. Compared with DC-bias caused by UHV DC project, the variation of transformer noise and vibration is much more frequent when there is direct current caused by UMTS. In this condition, degradation is more likely to happen in transformer mechanical structure.



(a) R versus time of transformer noise



(b) R versus time of transformer vibration

Figure 9: Time variation comparison of R feature with noise and vibration.

4. Conclusion

The main objective of this paper is to find some effective features to detect DC-bias in power transformers. The generation mechanism of DC-bias caused by UMTS is analyzed. The noise and vibration characteristics in both time- and frequency-domain are compared. Two features are extracted and employed to analyze the field test variation process of DC-bias. It is found that the amplitude rate of odd harmonics to even harmonics of 50Hz and the harmonic distortion rate are effective to detect DC-bias in transformers. Further investigation will be carried out in the future to quantify the relationship between the features and the direct current flowing into transformers.

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