Influence of Noise on Fault Diagnosis of Transformer based on Vibration Signal

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Abstract. Monitoring transformer vibration signals is a universal application method to realize the diagnosis of internal mechanical faults of transformers. However, the actual transformer operating is interfered by the noise of the surrounding electrical equipment, which reduces the accuracy of the vibration signal identification. This paper simulate the typical noise sources in the actual transformer operating environment, including fan noise and surrounding equipment fault noise, and explore the impact of different noise sources on the transformer vibration signal.

1. Introduction
As one of the methods of transformer fault diagnosis, vibration method has become a reliable transformer fault diagnosis technology that has developed rapidly in recent years [1-4]. The vibration signal of the transformer contains fault information of the transformer, but the transformer would also be interfered by the surrounding power equipment and noise signals in actual operation, which reduces the accuracy of the identification of the vibration signal. When the transformer is in operation, the main noise interference comes from the noise interference of its own cooling equipment [5, 6]. Reference [5] compares the frequency spectrum of the vibration signal when the fan is working and the frequency spectrum of the vibration signal when the fan is turned off in the actual transformer operation. The result shows that when the cooling fan is working, the vibration amplitude measured on the surface of the transformer box is There is a significant increase in the low-frequency area within 100z, which causes greater interference to signal processing and analysis. Therefore, it is of engineering significance to explore the interference influence law of multi-source environmental noise on transformer vibration signal and propose a countermeasure. This paper simulates the typical noise sources in the actual transformer operating environment and applies them to the transformer mechanical defect simulation test platform to obtain the vibration characteristics under different noise backgrounds and explore the influence of different noise sources on the vibration signal.

2. Transformer vibration mechanism
Transformer vibration is caused by the vibration of its internal iron core, windings and cooling device. At the same time, external environmental noise will also be transmitted to the surface of the transformer through the air to produce certain vibrations. The vibration and noise generation and propagation process are shown in Figure 1.
The winding vibration is mainly caused by the dynamic electromagnetic force of the coil passing the alternating current in the leakage magnetic field, and the vibration of the iron core is mainly caused by the magnetostriiction phenomenon of the silicon steel sheet and the electromagnetic force caused by the eddy current between the silicon steel sheets. The rotating frequency of the fan has a serious interference to the vibration signal of the transformer, and the working frequency of the fan is affected by the frequency of the power grid and mainly works in the low frequency area. Therefore, the superimposition effect produced causes the change of the overall frequency amplitude.

3. Feature extraction based on vibration signal
This paper first measures the vibration signals of the transformer in various operating states under different noise environments. Obtain the frequency domain diagram of the vibration signal by fast Fourier transform, and analyze the effect of noise on vibration signals.

The transformer vibration test system is shown in Figure 2, including a noise generating device, a piezoelectric acceleration sensor, a signal conditioner, a data acquisition card and an upper computer. The vibration sensor is fixed on the transformer shell through the magnetic base to obtain the vibration signal of the transformer, and it is installed at position ① in Figure 2; the interference noise around the transformer is simulated by the fan and audio equipment. The interference noise around the transformer is simulated by the fan and sound, and the noise source is 50cm away from the vibration sensor, installed at position ② in Figure 2. The signal is transmitted to the upper computer through the conditioner and data acquisition card, and then the state of the transformer is evaluated. The test transformer is a three-phase dual-winding transformer, as shown in Figure 3. In the experiment, 75% of the rated current at a frequency of 50 Hz was used to provide excitation for the three-phase transformer core model to obtain vibration characteristics; the reactor was connected in series to the capacitor ground loop to reduce current distortion. The state of the transformer includes three states: normal operation, loose winding fault and loose core fault. Noise is divided into two types: fan noise and equipment fault noise around the transformer. Among them, the fan noise is generated by the transformer fan, and the fault noise of the equipment around the transformer is generated by the audio equipment through collection.
In a noise-free environment, the vibration signals under the normal state, the loose winding fault state and the loose core fault state were measured respectively, and the frequency domain analysis of the measured signals is shown in Figure 4.

According to the frequency spectrum of the vibration signal calculated by the measurement, the following characteristic quantities can be obtained:

1) Fundamental frequency amplitude:
   The fundamental frequency $f$ of the vibration signal is twice the fundamental frequency of the current signal, so the fundamental frequency $f$ of the vibration signal is 100 Hz. After FFT processing, obtain the fundamental frequency amplitude $A_{100}$;

2) Fundamental frequency proportion:
   \[ P_{100} = \frac{A_{100}^2}{\sum_{f=100}^{\text{max}} A_f^2} \]  

In formula (1), $P_{100}$ is the fundamental frequency proportion; $f$ is the fundamental frequency of the vibration signal; $f_{\text{max}}$ is the maximum value of the fundamental frequency of the vibration signal; $A_f$ is the amplitude corresponding to the frequency $f$ in the vibration spectrum;

3) Vibration entropy:
   \[ H = \left| \sum_{f=100}^{\text{max}} P_f \log_2 P_f \right| \]  

$P_f$ is the specific gravity of the vibration signal at frequency $f$; $H$ is the vibration entropy of the vibration signal at the fundamental frequency $f$.

4. Analysis of noise interference to signal and fault identification

Under the noise interference of the fan, the vibration signals under the normal state, the loose winding fault state and the loose core fault state were measured. The frequency domain diagram is shown in Figure 5.

Comparing Figure 4, it can be found that the fan noise has a greater impact on the low-frequency amplitude of the transformer vibration signal, which is mainly realized as an increase in the fundamental frequency signal. In addition, there is also a small increase in the frequency of integer multiples of 100 Hz. The sound equipment is used to simulate the noise caused by equipment failures around the transformer, and the vibration signals of different states under the interference are measured. The frequency domain diagram is shown in Figure 6. Through the frequency domain diagram, it can be seen that the vibration signal within 1400 Hz will be affected by noise in various
By comparison with Figure 4, the frequency band within 200 Hz is greatly affected by noise, and the equipment noise around the transformer is also mainly concentrated in this frequency band. In addition, the fundamental frequency amplitude and the integral multiple of the fundamental frequency amplitude have also increased slightly, but compared to Figure 5, it can be found that the influence of the analog noise on the fundamental frequency amplitude is smaller than that of the fan noise.

According to the frequency domain diagrams of various operating states of the transformer under different noises, the characteristic quantities in each case are calculated, as shown in Table 1. According to the characteristic quantities of the transformer operating in different states under noise, the maximum interference of fan noise to the fundamental frequency amplitude is 38%, while the maximum interference of analog noise to the fundamental frequency amplitude is less than 19%. It shows that the fan has more interference to the fundamental frequency. Fan noise caused a 19% change in the fundamental frequency, while the analog noise had less than 12% of the fundamental frequency, which once again confirmed that the fan has a greater interference to the fundamental frequency. Since the influence of the fan on the frequency is mainly concentrated near 100Hz, and the proportion of the 100Hz frequency is increased, so that the signal frequency domain is more concentrated near 100Hz, so the vibration entropy is reduced. The fault noise of other equipment has an impact on each frequency band of the original signal, resulting in an increase in each frequency band, and a more scattered frequency, which leads to an increase in vibration entropy.

| Noise                      | State             | Fundamental frequency amplitude /g | Fundamental frequency ratio /% | vibration entropy |
|----------------------------|-------------------|-----------------------------------|--------------------------------|------------------|
| No noise                   | Normal            | 0.0270                            | 72.47                          | 1.35184          |
|                            | Loose winding fault | 0.0160                           | 52.06                          | 1.61092          |
|                            | Loose core failt   | 0.0326                           | 76.74                          | 1.25966          |
| Fan                       | Normal            | 0.0340                            | 82.24                          | 1.02712          |
|                            | Loose winding fault | 0.0221                          | 62.01                          | 1.51272          |
|                            | Loose core failt   | 0.0432                           | 77.34                          | 1.22306          |
| Simulated equipment fault | Normal            | 0.0271                            | 69.02                          | 1.62164          |
|                            | Loose winding fault | 0.0193                         | 54.44                          | 1.97819          |
|                            | Loose core failt   | 0.038                             | 67.54                          | 1.74994          |

5. Conclusion
This paper analyzes the interference effect of noise on the transformer vibration during the actual operation of the transformer. The interference of fan noise is particularly obvious. Therefore, when measuring the vibration signal of the transformer in practice, the position of the fan should be selected as far away as possible to reduce the influence on the measurement result. At the same time, the environmental noise around the transformer should be monitored, and the operating state of the transformer should be judged in combination with the environmental noise to improve the accuracy of fault diagnosis.

6. References
[1] JI Shengchang , ZHANG Fan , SHI Yuhang , ZHAN Cao , ZHU Yeye. , LU Weifeng, LU Weifeng. Review on vibration-based mechanical condition monitoring in power transformers[J]. High Voltage Engineering, 2020. 46(1): 257-272.
[2] YU Zhangting, LI Dajian, CHEN Liangyuan, et al. Transformer fault diagnosis technique based on voiceprint and vibration[J]. High Voltage Apparatus, 2019, 55(11): 248-254.

[3] WANG S, WANG S, LI H, et al. Mechanical characteristics analysis of defective transformer windings under shortcircuit fault using 3-D FEM[C]//International Conference on Electrical Machines & Systems(ICEMS). Sydney, NSW, Australia: IEEE, 2017: 1-4.

[4] Su Shiwei. Research on looseness fault of oil-immersed transformer based on vibration analysis method[D]. Huazhong University of Science & Technology, 2018.

[5] ZHAO Z Y, TANG C, YAO C G, et al. Improved method to obtain the online impulse frequency response signature of a power transformer by multi scale complex CWT[J]. IEEE Access, 2018, 6: 48934-48945.

[6] WANG Y, PAN J. Comparison of mechanically and electrically excited vibration frequency responses of a small distribution transformer[J]. IEEE Transactions on Power Delivery, 2017, 32(3): 1173-1180.