Anti-Interference Test Technology of Transformer Noise

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Abstract. In order to enhance the transformer noise test accuracy, an anti-interference method based on wavelet packet decomposition and spectral subtraction algorithm is proposed in this paper. The tested original noise signal is decomposed with the wavelet packet method. The occurring time and frequency bands of the noisy signals are observed. In these bands, the noisy signals are further processed by spectral subtraction method. Finally, the pure transformer noise is obtained with wavelet packet reconstruction. The anti-interference effects of transformer noises in the conditions of various interference sources and signal to noise ratios are simulated. The result shows that the proposed method is effective in restraining the influence of diverse burst intermittent environmental noises on the transformer noise test result.

Keywords: transformer, environmental noise, wavelet packet, spectral subtraction.

1. Introduction
Sound pressure level (SPL) test is an important task in the procedure to judge whether the noise emission of substation meet the law standard. However, outdoor noise test of power transformer is commonly influenced by its surrounding environmental interferences, which come from the noise of birds, insects, frogs, automobile, etc. These interferences will lead to large discrepancies between tested and actual results. Hitherto, many works have been reported about noise test results of power transformers [1-6]. In these papers, noise and vibration characteristics of power transformers are analyzed. However, few researches is found about anti-interference test technology in the noise test process of power transformers.

In this paper, an anti-interference methodology based on wavelet packet decomposition (WPD) and basic spectral subtraction algorithm is proposed. The anti-interference effects of transformer noises in the conditions of various interference sources and signal to noise ratios (SNRs) are simulated. The proposed method can be referenced when the pure transformer noise test is required in the environmental assessment process.

2. Proposed Method

2.1. Wavelet Packet Decomposition
A wavelet packet function can be defined as [7]
Where \( n \) is the modulation parameter, \( l \) is the scale level, \( k \) is the localization parameter.

The wavelet packet functions can be defined with the following sequence of recursive functions.

\[
W^{2n}(x) = \sqrt{2} \sum_k h(k) W^n(2x - k)
\]  

(2)

\[
W^{2n+1}(x) = \sqrt{2} \sum_k g(k) W^n(2x - k)
\]  

(3)

Where \( h(k) \) and \( g(k) \) are the low-pass and high-pass finite impulse filters, respectively.

### 2.2. Basic Spectral Subtraction

Spectral subtraction is an effective method to deal with broadband noise. On the assumption that the noise \( r(n) \) and the speech signal \( s(n) \) are independent of each other, the noise power spectrum \( P_n(\omega) \) is subtracted from the power spectrum \( P_s(\omega) \) of the noisy speech signal \( y(n) \) so as to obtain a relatively pure speech spectrum, as shown in Fig. 1. In the figure, \( \Psi(\omega) \) is the phase spectrum of the mixed noise signal.

The noisy signal is divided into frames, and the windowed Fourier transform of the \( \lambda \)th frame signal is as follows [8]:

\[
Y(k, \lambda) = S(k, \lambda) + R(k, \lambda)
\]  

(4)

Where \( P_y(k, \lambda) \), \( P_s(k, \lambda) \) and \( P_r(k, \lambda) \) are the power spectrum of the \( \lambda \)th frame of signals \( y(n) \), \( s(n) \) and \( r(n) \), respectively.

\[
P_y(k, \lambda) = P_s(k, \lambda) + P_r(k, \lambda)
\]  

(5)

Since the noise of transformer body is almost the same before and during the occurrence of external environmental noise, the power spectrum of transformer body noise can be estimated by the silent section when the environmental noise does not occur.

\[
P_s(k, \lambda) = \begin{cases} 
- P_y(k, \lambda) - P_r(k, \lambda), & \text{if } P_y(k, \lambda) > P_r(k, \lambda) \\
0, & \text{if } P_y(k, \lambda) < P_r(k, \lambda)
\end{cases}
\]  

(6)
3. Result and Analysis

3.1. Automobile Noise Interference
Taking the vehicle noise of expressway as the interference source, the SPL of 110kV main transformer ($s_1$) is 59.9 dB(A), and the vehicle noise interference signal is $s_2$. The noise signal ($s_m$) of the interfered transformer is obtained by linear mixing of the two. The SNR is 4.5dB and the sound pressure level is 68.2 dB(A). The actual transformer noise, interference source noise and their mixed noise signal waveforms are shown in Fig. 2. The mixed signal ($s_m$) is decomposed by 3-layer wavelet packet, and the decomposition result is shown in Fig. 3. In the figure, $s_1$ is the original signal, $S_{130}$~$S_{137}$ is the wavelet packet reconstruction signal of each decomposition frequency band.

![Figure 2. Transformer and automobile noises](image)

![Figure 3. WPD of the transformer noise with automobile-interference](image)
Except for the low frequency band $S_{130}$, the vehicle noise signal is distributed in the frequency band $S_{131}$~$S_{137}$. Generally speaking, the frequency of vehicle engine noise is low, and the main reason for the above distribution is that the friction between wheel and ground produces broadband noise. The spectrum subtraction method is used to filter the noise of $S_{131}$~$S_{137}$ frequency bands and the processed results are shown in Fig. 4. It can be seen from the figure that the vehicle noise interference in each frequency band is significantly suppressed. The transformer anti-interference detection value is 60.4 dB(A) and the error with the actual noise value of transformer is only 0.5 dB(A). The correlation of spectrum distribution is an important parameter to measure whether the noise signal of transformer is recovered effectively after anti-interference detection. The spectrum comparison between the actual transformer noise signal and the calculated value of transformer noise anti-interference detection is shown in Fig. 5. The similarity coefficient of the two spectra is 0.92.

![WPD of the transformer noise with automobile interference after noise reduction](image)

**Figure 4.** WPD of the transformer noise with automobile interference after noise reduction
In order to further prove the effectiveness of the anti-interference detection method, Table I shows the anti-interference detection effect with different SNRs. When the SNR is in the range of 4.5 dB ~ 23.3 dB, the maximum error is 0.5 dB (A), and the minimum error is only 0.1 dB (A).

| SNR/dB | Disturbed value/ dB(A) | Actual value/ dB(A) | Calculated value/ dB(A) | Error/ dB(A) |
|--------|------------------------|---------------------|-------------------------|--------------|
| 4.5    | 68.2                   |                     | 60.4                    | 0.5          |
| 7.4    | 65.8                   |                     | 59.5                    | 0.4          |
| 11.8   | 63.0                   | 59.8                |                         | 0.1          |
| 15.4   | 61.6                   | 60.0                |                         | 0.1          |
| 23.3   | 60.2                   | 60.0                |                         | 0.1          |

3.2. Multi-source interference
The actual test process of transformer noise is often interfered by a variety of external noises. Taking the multi-source noise of frog and insect as an example, this paper analyzes the anti-interference detection effect of transformer noise. Assuming the signal-to-noise ratio is only 2.2dB and the interference signal sound ($s_2$) pressure level is as high as 70.9 dB (A), the actual transformer noise, interference source noise and their mixed noise signal waveforms are shown in Fig. 6.
Figure 6. Transformer and multi-interference noises

The 3-layer wavelet packet, and the decomposition result of the mixed signal ($s_m$) is shown in Fig. 7. The multi-source interference noise is distributed in all frequency bands. Due to the small acoustic cavity of insects, the sound frequency rate of insect chirping is mainly in $s_{132}$–$s_{137}$ frequency band with $s_{132}$, $s_{134}$, $s_{136}$ and $s_{137}$ frequency band being the dominant bands. The noise frequency of frog chirping is lower than that of insect chirping, which is mainly in the bands of $s_{130}$, $s_{131}$, $s_{133}$ and $s_{135}$.

The above signals are filtered by spectral subtraction, and the processing results are shown in Fig. 8. It can be seen that the interference signal has been effectively suppressed. The spectrum comparison between the actual transformer noise signal and the calculated value of transformer noise is shown in Fig. 9. The spectrum correlation coefficient is 0.93, and the sound pressure level error is 0.9 dB (A).

Figure 7. WPD of the transformer noise with multi-interference
In the actual detection process of transformer noise, the intensity of interference signal is difficult to predict. In order to further analyze the detection effect of the algorithm, the detection results of
transformer noise under five SNR conditions are calculated, as shown in Table II. It can be seen that when the signal-to-noise ratio increases from 2.2 dB to 25.7 dB, the detection error of the algorithm for multi-source interference is stably controlled in the range of 0.9 dB (A), and when the signal-to-noise ratio is 5.7 dB, the detection error is the lowest, only 0.1 dB (A).

Table 2. Anti-Interference Test Results of Transformer Noises with Multi-Interference

| SNR/dB | Disturbed value/ dB(A) | Actual value/ dB(A) | Calculated value/ dB(A) | Error/ dB(A) |
|--------|------------------------|---------------------|-------------------------|--------------|
| 2.2    | 71.2                   | 59.9                | 60.8                    | 0.9          |
| 5.7    | 68.1                   |                     | 59.8                    | 0.1          |
| 11.7   | 63.7                   |                     | 59.2                    | 0.7          |
| 17.7   | 61.2                   |                     | 59.0                    | 0.9          |
| 25.7   | 60.2                   |                     | 59.0                    | 0.9          |

3.3. Discussion

There are many differences between transformer noise and environmental noise in time-domain waveform and spectrum distribution. Based on these differences, many anti-interference detection methods can be used.

The sudden environmental noise sources around the transformer can be divided into small cavity animal noise (such as birds, insects, etc.), large cavity animal noise (such as dog barking, etc.) and vehicle noise. Among them, the frequency of small cavity animal noise is higher than that of transformer noise in the frequency band of 50 Hz ~ 2 kHz. It is feasible to use low-pass filtering method for this kind of noise. However, for the latter two types of noise sources, the low-pass filtering method has poor processing effect. The main reason is that the frequency of the latter two kinds of environmental noise is low, and there is a lot of overlap with the frequency band of transformer noise. It is difficult to achieve good results with universal applicability only by using frequency-domain filtering method. Therefore, for the sudden intermittent environmental noise around the transformer, the combination of time domain and frequency domain anti-interference processing method is more appropriate.

The wavelet spectrum subtraction and the wavelet packet spectrum subtraction proposed in this paper belong to the same kind of methods, both belong to the anti-interference processing method of combining time domain and frequency domain. However, due to the differences in the characteristics of the algorithm, the former only divides the low-frequency part of the noise signal carefully, and it is difficult to detect the high-frequency part of the interference signal. Therefore, in theory, the effect of wavelet spectral subtraction is less than that of wavelet packet spectral subtraction.

Faced with the reality that the noise around the transformer is complex and changeable and the type of noise is difficult to predict, it can be expected that the advantages of the noise anti-interference detection method proposed in this paper will be more prominent.

4. Conclusion

Aiming at the problem that the noise detection result of transformer is easily interfered by the environmental noise, an anti-interference detection method of transformer noise combining WPD and BSS is proposed in this paper. The anti-interference detection effects of transformer noise under various common interference sources are compared. The comparison of different anti-interference methods such as low-pass filter and wavelet spectral subtraction are discussed. The main conclusions are as follows.

- Under the condition that the noise detection of transformer is interfered by the noise of surrounding vehicles, the maximum error of anti-interference detection of transformer noise is 0.5 dB (A) and the minimum error is only 0.1 dB (A) in the range of SNR 4.5 dB ~ 23.3 dB, and the correlation coefficient between the noise signal spectrum after anti-interference processing and the actual signal spectrum reaches 0.92.
• Under the condition that the noise detection of transformer is interfered by multi-source noise, the maximum error of anti-interference detection of transformer noise is 0.9 dB(A) and the minimum error is only 0.1 dB(A) in the signal-to-noise ratio range of 2.2 dB ~ 25.7 dB, and the correlation coefficient between the noise signal spectrum after anti-interference processing and the actual signal spectrum reaches 0.93.

• Compared with the low-pass filtering method and the wavelet spectrum subtraction method, the detection accuracy of the proposed method is higher, and it is more suitable for dealing with the complex and intermittent environmental noise interference in the field of transformer noise measurement.

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