Online monitoring research of transformer vibration based on labview

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Abstract. In order to study the influence of transformer core and winding fault on the vibration signal generated during the operation of power transformer, this paper establishes a transformer vibration online monitoring system based on labview software, and studies the vibration characteristics of transformer under different working conditions. Monitor transformer operating status by comparing the energy ratio of different frequency bands of the vibration signal. A vibration signal acquisition platform based on acceleration sensor is built in the monitoring system. The signal is collected for the vibration acceleration signal generated under different working conditions of the transformer. The cumulative probability distribution histogram and standard deviation of the acceleration signal are drawn. The acceleration signal is found to be random and its standard deviation will vary with the working state of the transformer. Therefore, the signal standard deviation can be compared with the normal operation of the transformer. If the phase difference is found to be large, it can be initially judged that the transformer operating state is abnormal. Then further analysis of the energy ratio of the different frequency bands to the total energy ratio can determine whether the transformer core and winding are faulty. The research results provide a new research idea for the design of transformer vibration signal monitoring system.

1. Introduction

With the development of economy, the demand for power quality is getting higher and higher, which requires the power transformer, one of the most important equipment in the power grid, to better complete the task of transforming, transmitting and distributing energy. At the same time, whether the power system is economical and reliable during operation is closely related to the power transformer. After the transformer has been used for a certain period of time, due to its complicated internal structure, various types of losses will cause the transformer to malfunction. Only the power system can accurately and timely monitor the running state of the transformer to ensure the reliable and safe operation of the power system.

At present, the traditional transformer condition monitoring method generally adopts off-line test detection and periodic maintenance of the transformer. This traditional method belongs to planned preventive maintenance, the operation needs to be powered off, does not meet the requirements of the economic operation of the power system, and the process is cumbersome. The obtained transformer status information has hysteresis and cannot meet the needs of modern state maintenance for real-time condition monitoring of the transformer [1]. The vibration method is a new method for monitoring and measuring transformer faults in recent years. The cause of transformer failure is largely caused by core
and winding faults [2-3], and the vibration signals of the core and winding are monitored online. It can monitor the working condition of the transformer in time and accurately [4-5].

Based on the labview software, this paper establishes an on-line monitoring system for transformer vibration. The effects of vibration and signal generated during the operation of the power transformer are studied. The vibration acceleration under different working conditions of the transformer is simulated in the simulation process. Based on the introduction of the cumulative probability distribution histogram and the signal standard deviation, the energy ratio of the different frequency bands of the signal is analyzed in combination with the “band-energy method”. The research results show that the vibration signal of the transformer fault and the normal operation of the transformer. The vibration signal produces a significant difference in the proportion of energy distribution in different frequency bands to determine if the transformer is faulty. The research results are of great significance to the design concept of the transformer vibration signal monitoring system.

2. Simulation of vibration signal of power transformer

2.1 Characterization of vibration signals

The labview software is used to realize the acquisition and measurement of the vibration signal of the power transformer. The basic method is finite element analysis. Since the power transformer analyzes and processes the collected signals and evaluates the running state of the windings and the iron core, abnormal defects such as winding deformation and loose core can be found in time. In the process of signal acquisition, the accelerometer is used to collect the acceleration and vibration of the winding and core of the power transformer. In this case, the phase difference of the vibration acceleration generated by the transformer winding and the core is calculated as shown in Equation (1) [6].

\[ \phi = 2\phi_0 + \beta - \frac{\pi}{2} \]  

\[ \phi_0 \] and \( \beta \) sequentially represent the initial value of the load current of the power transformer winding and the winding parameters under fixed conditions.

The \( a_w \) (winding vibration acceleration) and \( a_c \) (core vibration acceleration) are used as the vibration source, and the vibration acceleration amplitude calculation formula of the vibration radiation generated is as shown in the following formula (2).

\[ a = (a_c^2 + a_w^2 + 2a_c a_w \cos \phi)^{1/2} \]  

The following relationship exists between the vibration acceleration amplitude and \( a_c \) and \( a_w \).

\[ |a_c| - |a_w| \leq a \leq |a_c| + |a_w| \]  

The vibration acceleration level can be expressed as the intensity of the vibration, and the similar form of the noise level can also express the vibration acceleration series, as shown in the following formula [7].

\[ L_a = 20\log \frac{a}{a_0} \]

In the above formula, \( a_0 \) is expressed as a reference value of the vibration acceleration, and the detection accuracy can be set to \( 10^{-3}\text{ m/s}^2 \) according to the nature of the transformer.

Since the vibration of the power transformer box is a very complicated process, it is generally necessary to take into account various influencing factors when performing the transformer vibration test program. In the test, the installation position of the acceleration sensor in the transformer tank body has a great influence on the measurement results. Therefore, when test the different types of transformers, the actual arrangement of the sensors should be planned according to the internal structure and the external design of the transformer.

2.2 Extraction and analysis of vibration signals

In this study, the vibration signal extraction usually includes acquisition and measurement, which can be finished by the NI configuration software. We can use the NI MAX module of NI configuration
software to analog power transformer vibration signal. NI MAX module can identify and detect NI hardware, implement data acquisition and automatically import the acquired signals into labview software. After filtering, you can directly observe the cumulative probability distribution histogram and standard deviation of the vibration acceleration under different working conditions in the labview software.

Figure 1. Histogram of cumulative probability distribution of vibration signals when the transformer is in normal operation.

Figure 2. Histogram of cumulative probability distribution of vibration signals when the transformer is in a mild fault.

Figure 3. Histogram of cumulative probability distribution of vibration signals when the transformer is in a moderate fault.
Figure 4. Histogram of cumulative probability distribution of vibration signals when the transformer is in a severe fault

Table 1. Standard deviation of vibration signal under different working conditions of transformer

| Operating status     | Standard deviation |
|----------------------|--------------------|
| normal operation     | 0.7483             |
| mild failure         | 0.6163             |
| moderate failure     | 0.4299             |
| severe failure       | 0.3238             |

Observed that the distribution of vibration signal in the cumulative probability distribution of the transformer is in a concentrated trend when the transformer is in different working states. As the transformer fault condition increases, the standard deviation of the vibration signal amplitude gradually decreases, indicating that the monitoring is in the process of fault aggravation. The vibration signal of the transformer is affected by the noise more and more serious. Therefore, whether the transformer is abnormal can be judged by comparing the standard deviation of the amplitude of the vibration signal when the transformer is in fault with the standard deviation of the amplitude of the vibration signal when the transformer is in normal operation. If it is judged that the transformer is abnormal, it is necessary to immediately stop supplying power to the transformer and perform offline maintenance. Before the maintenance, the vibration signal is wavelet transformed to obtain the energy ratio of different frequency bands of the vibration signal, and compared with the energy ratio distribution of the transformer during normal operation, it can be determined whether the transformer winding and the core are faulty. The flow chart of transformer vibration signal extraction and analysis is shown in Figure 5.
Figure 5. Flow chart of transformer vibration signal extraction and analysis.

3. Wavelet transform of vibration signal

3.1 Overview of Wavelet Transform Theory

As a new method for analyzing time-frequency, which has been developed in recent years, wavelet analysis is widely used in signal processing. The essence of this method is the so-called wavelet transform analysis method, which is mainly reflected in the ability to reflect the salient features of some problems by means of wavelet changes, so it has been rapidly applied in related fields.

When the wavelet transform is continuously performed, if the $\Psi(x)$ function satisfies the following condition [8]:

\[
\Psi(x) \text{ satisfies the following condition: }
\]
At this time, it is indicated that the function is an allowable wavelet, and the following equation (6) is obtained by integrating the function.

\[ (W_\psi f)(a,b) = \left| \frac{1}{a} \int f(x) \psi(\frac{x-b}{a}) \, dx \right|, f(x) \in L^2(R) \quad (6) \]

The integral change in the above Equation 6 is mainly expressed as \( \psi(x) \) transformation of \( f(x) \). Where \( L^2(R) \) is expressed as the integrable function of the equation at the \( R \) level, which is the wavelet function in this study; \( a \) and \( b \) are expressed as scale factor and time level factor respectively, both of which are real numbers, and \( a \neq 0 \). Generally speaking, in practical applications, when \( a < 0 \), it means that it has no meaning at this time, and the \( a \) and \( b \) parameters generally selected in the wavelet transform in different fields are also different.

If \( \psi(\omega) \) is continuous, it is easy to get

\[ \int_{-\infty}^{+\infty} |\psi(t)| \, dt = 0 \quad (7) \]

In the above formula (7), \( \psi(t) \) is also called a mother wavelet, which can form a standard orthogonal basis by means of telescopic translation.

Obviously, not all functions can determine the expression \( f \in L^2(R) \) after the transformation has a certain meaning. Moreover, in practical situations, especially in applications where image and signal processing are performed, the purpose of changing the expression is simply to simplify the problem, and finally it is necessary to return to the original problem and solve it. To this end, we generally also need to ensure that continuous wavelet transform can be reversibly exchanged. In addition, in order to ensure fast attenuation between the window frequency and the time window, it is generally necessary to ensure that the window function meets the following conditions.

\[ \frac{|\hat{\psi}(\omega)|}{\omega} \leq C(1 + |\omega|)^{-1-\varepsilon} \]

\[ \frac{|\hat{\psi}(\omega)|}{\omega} \leq C(1 + |\omega|)^{-1-\varepsilon} \quad (8) \]

In equation (8), \( C, x \) and \( \omega \) are all independent constants, where \( \varepsilon \) is a positive number.

In essence, wavelet transform is a localized analysis method, which mainly changes the time-frequency window, but its window size does not change. According to research, it has high frequency resolution, low time resolution and high time resolution, low frequency resolution in the high frequency part and the low frequency part respectively. So we can find that wavelet analysis has the adaptability of the signal [9].

### 3.2 Wavelet transform processing signal advantages

In the traditional Fourier transform analysis process commonly used in previous analysis, the signal is generally fully expanded in the frequency domain, and the signal does not contain any time-frequency information after the signal is expanded. Therefore, it is very suitable for some relatively stable periodic signals. However, for some unstable signal analysis, the time domain information it discards is extremely important, so the effect of Fourier analysis is not ideal.

Wavelet analysis is based on the Fourier analysis method and is an extension of the Fourier analysis method. Moreover, this analysis method has always maintained a close relationship with the Fourier transform analysis. This method shows that it exists in the Fourier transform analysis method, and there are both commonalities and some differences. Mainly in the wavelet analysis method, compared with Fourier analysis, it can perform multi-resolution analysis. At the same time, it shows certain local information representation ability in frequency domain and time domain, while frequency window and time window, they are all adjusted according to the difference in the signal. Under normal conditions. The low frequency portion usually promotes its frequency resolution at a lower time resolution. vice versa. Based on the above characteristics, wavelet analysis can detect and analyze transients in normal
signals, and it can also display the components of its frequency.

For the frequency generated under the condition of voltage transformation, because the signal is not very stable, and the wavelet has certain frequency domain and time domain resolution characteristics, it can obtain the time domain characteristics in each frequency band. Therefore, it can provide more effective support information for post-fault diagnosis. Therefore, the choice of wavelet transform is more obvious than the traditional Fourier transform analysis [10]. In the actual situation, when the wavelet transform of the transformer vibration signal is used, the multi-resolution property of the wavelet is usually used to realize the signal quantitative processing processing. In this way, we can obtain the energy-vibration signal band distribution diagram of the transformer. Through the intuitive analysis of the diagram, the winding and core failure of the transformer can be directly judged.

3.3 Band-Energy Method

The multi-frequency analysis in the wavelet theory is applied to the vibration signal, and the scale is adjusted during the analysis to quantify the energy of different frequency bands, thereby drawing the frequency-energy spectrum of the collected transformer vibration signal [11-12]. When the power transformer is in normal working condition. Most of the generated vibration signal energy is in the low frequency range of 100~800 Hz; when the core or winding of the power transformer fails, the high frequency component of the vibration signal increases significantly, which leads to an increase in the proportion of energy, and at the same time, due to the conservation of the total energy, therefore, the proportion of energy in the main frequency band decreases. The energy of each frequency band of the vibration signal generated under the normal working state of the transformer is defined as a reference fingerprint vector. When the energy of the main frequency band is detected to be lower than the standard threshold or the energy of the high frequency band (greater than 800 Hz) is higher than the standard threshold, the power transformer is evaluated for failure. And the fault condition can be monitored in real time.

The advantage of the frequency band-energy method is that it can determine the proportion of each frequency band in the total energy according to different scale wavelet analysis to determine the main frequency band, and find the frequency band of the signal that generates the fault to determine the cause of the fault. However, its shortcoming is that it is necessary to determine the standard threshold, but the standard threshold needs to be determined in the long-term experiment according to specific parameters such as transformer model, capacity, and field operation and maintenance experience.

The four-layer wavelet decomposition of the vibration signal during the normal operation and the fault of the transformer is performed separately, and then the energy analysis is performed to grasp the proportion of the energy of the frequency band in the total energy of the transformer in two different states, and then according to the value, we can obtain an energy-band map. When the scales are different, the energy ratios of vibration signals in different frequency bands are different after wavelet analysis. For example, analyze the vibration signal when the transformer is working normally and the transformer is in moderate faulty. The energy ratio data corresponding to each frequency band is shown in Table 2. The energy spectrum of the two bands is shown in Figure 6 below. The left picture represents the frequency band-energy diagram of the transformer during normal operation, and the right picture represents the frequency band-energy diagram of the transformer failure. In the figure, black and white represent the percentage of the energy of the low frequency component and the high frequency component in the total energy of the vibration signal.

| Scale | Low frequency energy ratio (%) | High frequency energy ratio (%) |
|-------|-----------------------------|-----------------------------|
|       | Normal | Moderate failure | Normal | Moderate failure |
| 1     | 94.65  | 83.79           | 5.35   | 16.21           |
| 2     | 91.96  | 75.65           | 2.69   | 8.14            |

Table 2. The proportion of energy corresponding to each frequency band obtained after wavelet analysis at different scales.
4. Summary
On-line real-time monitoring of transformer faults can be achieved by monitoring the vibration signal of the power transformer, and since the Fourier transform has limitations in processing the signal, it is necessary to introduce a wavelet transform to process the signal. The data statistics obtained after wavelet analysis of the transformer vibration signal can preliminarily judge whether the anomaly is abnormal, and then combine the multi-frequency of the wavelet theory to quantify the energy of the signal frequency band. In this process, the high-frequency component can be obtained according to the wavelet transform of different scales. The ratio of the percentage of energy occupied by the percentage of low-frequency energy is compared with the normal energy threshold of each frequency band of the transformer vibration signal to determine whether the transformer core and the winding are faulty, and the purpose of online monitoring of the power transformer is achieved.

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