Foreign Body Detection and Analysis in Gas Insulated Switchgear Based on Vibration Signal

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Abstract. Maintenance tools are often left inside the equipment in the process of installation and maintenance of Gas Insulated Switchgear (GIS). Vibration detection can make up for the shortcomings of foreign body detection in traditional GIS to a certain extent. In this paper, the vibration signal during the operation of the circuit breaker is collected and analyzed based on the 330kV GIS test platform. Through the method of Ensemble Empirical Mode Decomposition (EEMD), by comparing with the multiple measurement results between the two cases of whether there is a foreign body in the equipment or not, it is found that there is a great difference in the characteristics of the two kinds of vibration signals. The presence of most foreign objects can be detected by the above methods.

Keywords: GIS; Foreign Body; Vibration Detection; Ensemble Empirical Mode Decomposition.

1. Introduction

As one of the important equipment in the GIS, the high-voltage circuit breaker controls the current in the power system, whose reliability affects the stability of the whole power system work[1-4]. In the process of installation and maintenance of GIS, tools are often left in the equipment. The operation of the circuit breaker operator generates the vibration signal and transmits it in the equipment shell[5-6]. In the same state, the signals collected repeatedly in the equipment shell are similar, and the measured vibration signal can be used to analyze the mechanical characteristics of the circuit breaker[7-10].

In recent years, with the development of high voltage technology and algorithm[11-14], scholars have studied the vibration characteristics of GIS shell. T.L Xu[15] used the time spectrum and marginal spectrum of Hilbert-Huang transform to diagnose the faults of GIS equipment. H. Zheng and others[16] studied the shell vibration characteristics of GIS based on the Empirical Mode Decomposition (EMD) algorithm.

When a foreign body exists in the GIS, the vibration signal measured by the equipment shell will be changed to a certain extent, and it is difficult to evaluate the equipment state with direct comparison, so some data processing method is required to conduct further analysis of the vibration signal[17-19]. This paper introduces the principle of EMD, combines the energy entropy, collects and analyzes the shell vibration signal of the 330kV GIS test platform, and proposes the detection method of GIS switch and cavity mechanical defects.

2. Basic Parameters of the Test Platform and the Equipment

The test platform adopts 330kV GIS test platform, mainly including 363kV SF₆ circuit breaker, isolation switch, bus bar, current transformer, voltage transformer, etc.. The overall structure diagram...
of the test system is shown in Fig. 1. After switching and closing, the operating mechanism will produce vibration excitation signal, causing vibration in the shell of GIS, and passes the vibration through the GIS components. The vibration acceleration sensor is arranged in the equipment housing to record the vibration response signal, collect the acquisition card, and transmit the signal to the top machine for storage, and conduct data processing after the field test.

The test aims to explore the influence of foreign body in GIS on the vibration characteristics of GIS shell. During the test, the foreign body was placed at the bottom of the bus cylinder and placed at the point in Fig. 2. The foreign objects used in the test mainly include flashlight, screwdriver, hammer, wrench and bolts. Among them, the overall density of the flashlight is small and the volume is relatively large. The screwdriver is of moderate quality and has an uneven quality distribution. The quality of the hammer is large and has uneven mass distribution. Different types of wrenches are helpful to exploring the influence of foreign bodies on the vibration characteristics of the shell. The density of the bolts is small and the volume is small.

Common vibration acceleration sensors include piezoelectric acceleration sensor, piezoelectric resistance acceleration sensor and capacitive acceleration sensor, among which the piezoelectric acceleration sensor is widely used in vibration acceleration measurement due to its low price, high sensitivity, light weight and convenience to carry.

The piezoelectric vibration acceleration sensor works on the piezoelectric effect. There is a piezoelectric crystal sheet inside the sensor. When the piezoelectric crystal plate is stressed, the surface of the piezoelectric crystal accumulates. The insulation resistance of the piezoelectric crystal sheet itself is very high, giving the crystal sheet a parallel plate capacitor structure with a capacitance as formula (1).

\[ C_a = \frac{\varepsilon A}{d} \]  

The relationship between the voltage amount generated on the crystal sheet and the acting force on the crystal sheet is shown in formula (2).

\[ e_a = q = \frac{d d}{\varepsilon A} F = \frac{d d}{\varepsilon A} F_m \sin \omega t \]  

In the formula (2), \( \varepsilon \) is the dielectric constant of the piezoelectric crystal, \( A \) is the area of the crystal sheet, \( d \) is the thickness of the crystal sheet, \( d_1 \) is the piezoelectric coefficient, and \( F \) is the force applied along the crystal axis. After the crystal sheet of the piezoelectric accelerometer is determined, the \( \varepsilon, d, d_1, A \) is constant, and the voltage amount generated on the crystal sheet is proportional to the acting force. The above features of piezoelectric vibration acceleration sensor all meet the test requirements of the vibration signal of GIS enclosure, and therefore are used in GIS switch and cavity mechanical defect detection system.

3. Data Analysis Method

3.1. Detection System Analysis Process

In this paper, a data processing method based on EEMD-energy entropy is adopted, with the analysis
principle of treating the anomaly-free signal distribution measured on the surface of the device as a uniform distribution and that measured in the presence of anomalies in the device. According to the definition of the entropy, the entropy can measure the degree of the signal chaos, so the data processing method based on the EEMD-energy entropy can partly reflect the deviation of the fault signal relative to the normal signal. The detection principle flow diagram of GIS switch and cavity mechanical defect detection system is shown below. The detection principle flow diagram of GIS switch and cavity mechanical defect detection system is shown in Fig. 3.

![Figure 3. Schematic flow diagram of GIS switch and chamber mechanical defect detection system](image)

3.2. EEMD

The directly measured signal is a time-domain signal, whose signal type is a shock signal and a non-steady state signal, so the analysis method applicable to the nonlinear and nonstationary signal is required. Empirical modal decomposition method is an adaptive signal time-frequency processing method that can decompose a complex nonstationary signal into a series of single-component stationary signals, namely the intrinsic modal function. Traditional Fourier decomposition methods have large limitations for the analysis of nonstationary signals, so the EMD method is suitable for acoustic vibration signal analysis for GIS switching operations.

The deficiency of the EMD approach is the existence of modal stacking, improved by EEMD. The Gaussian white noise $n_i(t)$ is added to the original signal, whose mean is zero and the amplitude standard difference is constant, and the added white noise has the statistical characteristics of frequency uniform distribution, which can reduce the degree of modal aliasing.

$$x_i(t) = x(t) + n_i(t)$$  \hspace{1cm} (3)

The EMD decomposition of a series of signal $x_i(t)$ yields the intrinsic modal function IMF component $c_{ij}(t)$ and the remainder. $c_{ij}(t)$ is the $j$ times IMF obtained after $i$ times adding Gaussian white noise. Repeat the above process many times and perform the overall average operation to eliminate the influence of Gaussian white noise, and finally get the series of IMF: $s$ of the following by EEMD decomposition.

$$c_j(t) = \frac{1}{N} \sum_{i=1}^{N} c_{ij}$$  \hspace{1cm} (4)

The resulting intrinsic modal function components are arranged from high frequency to low frequency, and will vary with the original vibration signal $x(t)$. The EEMD decomposition process is shown in Fig.4.

![Figure 4. Flow chart of EEMD](image)
Fig. 5 shows the vibration signal measured on the surface of the GIS bus shell under normal state. After EEMD decomposition of multiple IMF main components, the first five components are selected, and the result is shown in Fig. 6.

![Time domain waveform of vibration signal of GIS bus housing under normal state](image1)

![First five major IMF main components via EEMD decomposition](image2)

### 3.3. Seek Signal Envelope by Hilbert Transform

The envelope of the signal is capable of reflecting many mutation information of the signal. In the field of signal processing, the Hilbert transform method is a common method of obtaining the signal envelope. For the time domain signal $x(t)$, its Hilbert signal is defined as formula (5).

$$ g(t) = x(t) + jH[x(t)] $$

The Hilbert transform where $g(t)$ is $x(t)$, and the $g(t)$ amplitude is shown in formula (6).

$$ A(t) = \sqrt{s^2(t) + H^2(x(t))} $$

In the formula, $A(t)$ is the envelope of the signal $x(t)$. For the first five IMF components, the signal envelope waveforms are shown in Fig. 7.

![First five IMF component envelopes](image3)

### 3.4. Energy Entropy

Information entropy can reflect the degree of order of the system, the energy entropy in the information entropy can express the state of the signal, and the common energy entropy calculation methods are as formula (7).

$$ H = -\sum_{i=1}^{N} \varepsilon(i) \log_2(\varepsilon(i)) $$

Among them, $\varepsilon(i)$ is the result of a normalized treatment of the signal energy. A set of energy entropy obtained after the measured signal is treated as the eigenvectors of the signal. Finally, the two eigenvectors are compared through similarity analysis.
4. Results and Analysis
Considering the actual situation of the project, various foreign bodies were selected in the test, and they were placed at three points for several tests. Take the multiple measurement results on the measurement point when the foreign objects are placed in the bus cylinder, analyze the similarity results according to the above method, average the obtained results, and draw the similarity comparison diagram of various foreign bodies when placed at different points, as shown in the Fig.8.

![Figure 8. Similarity analysis results of different types of foreign bodies when placed at different points](image)

In the Fig.8, the Euclidean distance analysis result for no foreign body inside the GIS is 0.0157 because the similarity analysis between the measured signal waveforms are conducted and averaged in the data analysis, and because of the difference between multiple signal waveforms, the Euclidean distance analysis results are not zero with no foreign matter.

Observe the results of all foreign objects in the figure, and the Euclidean distance is closer to the type of foreign objects, while the analysis of the three foreign objects was more concentrated. Large, medium and small wrench types were used in the test. With the larger wrench placed into the GIS, the vibration signal measured on the shell surface increased significantly and Euclidean distance from the vibration signal without foreign matter. According to the definition of Euclidean distance in the article, the calculated result is the distance between the two eigenvectors, and the greater the value of the result, the greater the distance between the two eigenvectors, the more the difference. Therefore, the greater the wrench, the greater the impact on the internal structure of the bus cylinder, and the greater the characteristic vector difference between the vibration signal measured on the equipment shell surface and the vibration signal in the absence of a foreign body.

Combined with the results in the figure, when the Euclidean distance calculation result between the measured vibration signal and the normal signal is greater than 0.025, exception may occur inside the measured device. Through the measurement and analysis of the equipment housing vibration signal during the operation of the circuit breaker.

5. Conclusion
This paper studies the vibration of the equipment shell when there are foreign objects inside the equipment during the operation of the GIS operating mechanism, and analyzes the vibration signals through data processing methods such as EEMD. The results show that this data processing method can reflect the deviation of the fault signal from the normal signal to a certain extent. When there are foreign objects inside the device, the vibration signal characteristics measured on the surface of the shell are quite different from the normal signal. Through the measurement and analysis of the vibration signal of the shell during the operation of the circuit breaker, most of the foreign bodies can be detected by the above methods.

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