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Analysis of Insulator Leakage Current Characteristic

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Abstract

Insulator leakage current contains abundant insulator pollution information. Therefore, Hilbert-Huang transform is proposed to study the characteristic quantity of insulator leakage current. The pollution flashover test was carried out in the artificial fog chamber, and the development of pollution flashover of porcelain insulators was divided into three stages, namely, the initial discharge was stage one, the through discharge was stage two, and the flashover was stage three. Hilbert spectrum, intrinsic mode function component and time-frequency entropy of leakage current in three stages are analyzed. The results show that the frequency distribution of Hilbert spectrum of insulators is in the range of 0~150Hz and 200~250Hz. The intrinsic modal function components of stage 1 and stage 3 are more than those of stage 2. The time-frequency entropy of leakage current data before insulator flashover is always greater than that after flashover.

Keywords

Insulator; Leakage Current; Hilbert-Huang Transformation.

1. Introduction

Overhead transmission lines are exposed to the air all the year round, and the insulator will be affected by the environmental quality, and the surface of the insulator will accumulate a lot of pollution. In a certain weather conditions, such as wet weather, drizzle, melting ice, increase the conductivity of the insulator surface soluble, the insulation performance of insulators will be greatly reduced, the voltage applied to the surface of the insulator will produce discharge phenomenon, flashover accident occurs seriously [1-3]. At present, there are many literatures analysis the insulator leakage current. The literature using Fourier transform on the leakage current spectrum analysis [4-6]. The wavelet transform analysis of the insulator leakage current linear frequency modulation is carried out [7]. These methods have their limitations. Fourier transform applies only to stationary signals with linear transformation. There are obvious shortcomings in non-stationary signal processing. Wavelet analysis will greatly influence the analysis results because of the different wavelets.

In this paper, Hilbert-Huang transform was utilized to analyze the leakage current signal [8-11]. The HHT, Hilbert marginal spectrum and Hilbert time-frequency diagram and time-frequency entropy were used to analyze the leakage current signal. Characteristics of insulator leakage current in different discharge phases were studied, and the intrinsic mode function (IMF) component and time-frequency entropy feature quantity was extracted, which can be used to study the insulator pollution flashover.

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2. Experimental equipment and method

2.1 Experimental equipment and samples

2.1.1 Experimental equipment

Experimental schematic diagram is shown in Figure.1. According to the standard IEC60507 [12], the porcelain insulator were vertically suspended in the 5m × 5m × 5m of the artificial fog room, the high voltage was provided by the 2250kVA/1000kV two-frequency test transformer. High voltage wire passed through the wall into the fog chamber. Leakage current were converted to voltage signal by the current sensor, and then the acquisition system monitored and recorded voltage signal, current signal at sampling frequency of 100 kS/s. The humidity in the experiment process was produced by the automatic fog generator, and temperature and humidity were measured synchronously.

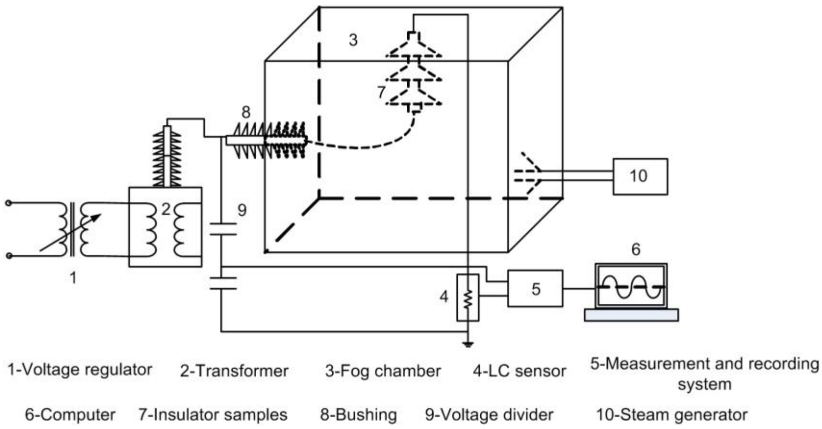

Figure 1. Schematic diagram

2.1.2 Insulator Sample and Experimental Methods

The XP-70 porcelain insulator was used to measure the LC in the test. The detailed dimensions of the porcelain insulator were tabulated in Table 1.

Table 1. Dimensions of porcelain insulator sample

Parameters	Dimensions in mm
Maximum disk Diameter	255
Creepage distance	295
Axial Height	146

The solid layer method described in IEC60507 was used in this test. The insulator was cleaned with deionized water before smeared. NaCl was mixed with Kaolin powder in a certain proportion in distilled water, which was coated on the insulator surface after it was dry. Finally, pre-contaminated samples were hung to keep airing for more than 24 hours in the laboratory before starting experiment.

2.2 Hilbert-Huang Transform Principle

The Hilbert-Huang transform consists of empirical mode decomposition (EMD) and the Hilbert spectrum analysis [13-14]. Firstly, the original signal is decomposed into several intrinsic mode components (IMF) by empirical mode decomposition, and then the Hilbert-Huang transform is performed for each IMF, and the instantaneous frequency spectrum, instantaneous amplitude spectrum and the Hilbert spectrum are obtained.

2.2.1 Empirical Mode Decomposition

In the Hilbert-Huang transform, in order to calculate the instantaneous frequency, an intrinsic modal function is defined. The EMD method decomposes a complex signal into a number of intrinsic modal

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functions, it is based on the assumption that any complex signal is made up of a number of distinct intrinsic modal functions, each of which is linear or non-linear, they have the same number of extreme points and zero-crossing points, and there is only one extreme point between adjacent zero-crossing points [15-16]. The intrinsic modal function satisfies two conditions. Firstly, in the whole dataset, the number of extreme points must be equal to that of zero-crossing points, or differ at most by one; Secondly, at any point, the average value of the upper and lower envelopes is zero,which is formed by the local maximum point and the minimum point.

Under the above-mentioned conditions, the EMD extracts the first IMF by the following sifting processes [17].

(1) The local maximum points and local minimum points of the signal $x(t)$ are determined. All the local maximum points are connected with the cubic spline curve to form the upper envelope $U_x(t)$ of the original waveform, and all local minimum points are connected by a cubic spline to form the lower envelope of the original waveform.

(2) The average value of the upper and lower envelopes is obtained

$$m_1(t) = \frac{U_x(t)+V_x(t)}{2} \tag{1}$$

(3) Find the difference between the original signal and the average of the upper and lower envelopes:

$$h_1(t) = x(t) - m_1(t) \tag{2}$$

(4) To test whether $h_1(t)$ satisfies the zero crossing condition and mean condition of the IMF component, and the mean condition is judged by the threshold value, and the range of threshold value is 0.2~0.3.

If it is not satisfied, treat $h_1(t)$ as the signal and iterate on $h_1(t)$ through steps 1–3. The stopping condition is $h_1(t)$ meet the above conditions, Consider $h_1(t)$ as the first component:

$$c_1(t) = h_1(t) \tag{3}$$

(5) Original signal $x(t)$ minus $c_1(t)$, the residual component $r_1(t)$ is obtained:

$$r_1(t) = x(t) - c_1(t) \tag{4}$$

Then repeat the above steps on the residual components to obtain a second IMF component $c_1(t)$, repeated n times to get n components. The original signal $x(t)$ can be expressed as:

$$x(t) = \sum_{i=1}^{n} c_i + r_n \tag{5}$$

2.2.2 The method of Hilbert transformation

Once the IMFs have been obtained by the EMD method, the Hilbert transform is performed to each IMF component as follows:

$$c_i(t)' = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{c_i(\tau)}{t-\tau} d\tau \tag{6}$$

Analytic signals $z_i(t)$ in complex domain is defined as:

$$z_i(t) = c_i(t) + jc_i(t)' \tag{7}$$

The amplitude is:

$$a_i(t) = \sqrt{c_i{}^2(t) + c_i{}^2(t)'} \tag{8}$$

The phases are:

$$\theta_i(t) = arctan\frac{c_i(t)'}{c_i(t)} \tag{9}$$

The instantaneous frequency is:

$$f_i(t) = \frac{1}{2\pi}\frac{d\theta_i(t)}{dt} \tag{10}$$

The original signal $x(t)$ is expressed as:

$$x(t) = Re\sum_{i=1}^{n} a_i(t)\, e^{j\int \omega(t)dt} \tag{11}$$

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The Hilbert spectrum is obtained by transforming the amplitude component and the frequency component.

2.3 Concept of Time-Frequency Entropy

Information entropy is used to measure the expected value of a random variable, the information entropy of a variable is greater, the more situations appear, that is, the more content contains, we need more information to determine this variable. (P_1, P_2 ... P_n) is the probability for random variable S (S_1, S_2 ... S_n):

$$s(p) = -a\sum_{i=1}^{N} p_i \, lnp_i \tag{12}$$

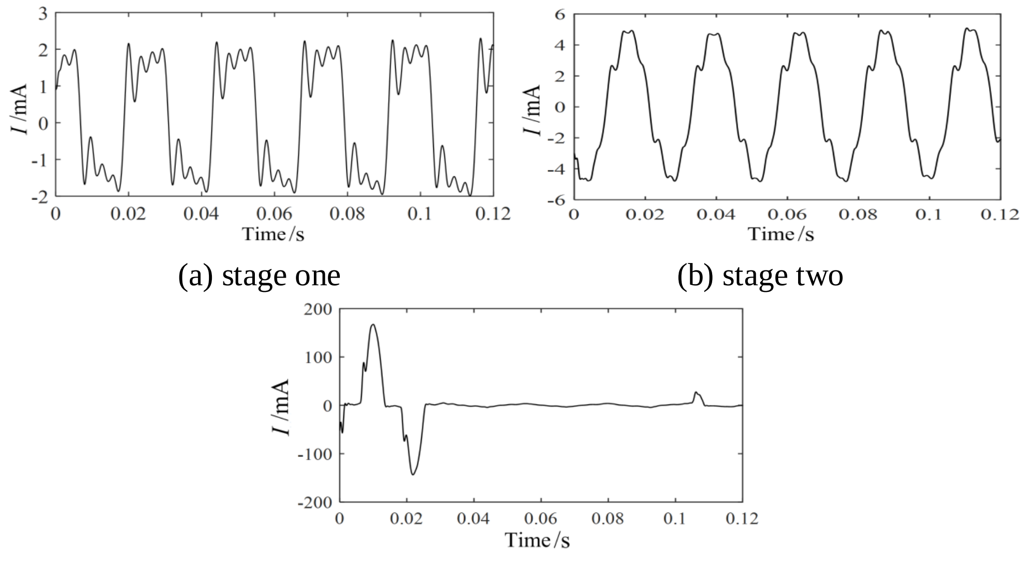
As is well known, the information entropy is greater, the variable contains more information, the uncertainty of the variable is greater and vice versa. Hilbert spectrum can reflect the change of signal amplitude with time and frequency, the time-frequency distribution of the leakage current signal at different state performs distribution of difference in small energy blocks in time-frequency plane, the uniformity of the energy distribution reflects the different stages of the insulator pollution flashover. In order to describe this difference, the information entropy is introduced into the Hilbert-Huang time-frequency distribution. The time-frequency plane of the Hilbert spectrum is divided into N blocks of equal area. The energy in each block is $W(i)(i=1,2,\ldots,N)$, The energy of the whole time-frequency plane is A, the energy is normalized for each block to get $q_i = W_i/A$, according to the formula of information entropy, Hilbert-Huang transform time-frequency formula is:

$$s(q) = -\sum_{i=1}^{N} q_i \, lnq_i \tag{13}$$

In the formula, $\sum_{i=1}^{N} q_i = 1$, the normalization condition of the information entropy is satisfied. According to the nature of information entropy, the distribution of q_i is more uniform, the value of time-frequency entropy $s(q)$ is larger, Otherwise the time-frequency entropy $s(q)$ will be smaller.

3. Results

The leakage current of the insulator is recorded in three different discharge stages, the initial discharge is stage one, the through discharge is stage two, and the flashover is stage three. And the waveform of leakage current is shown in Figure.2:

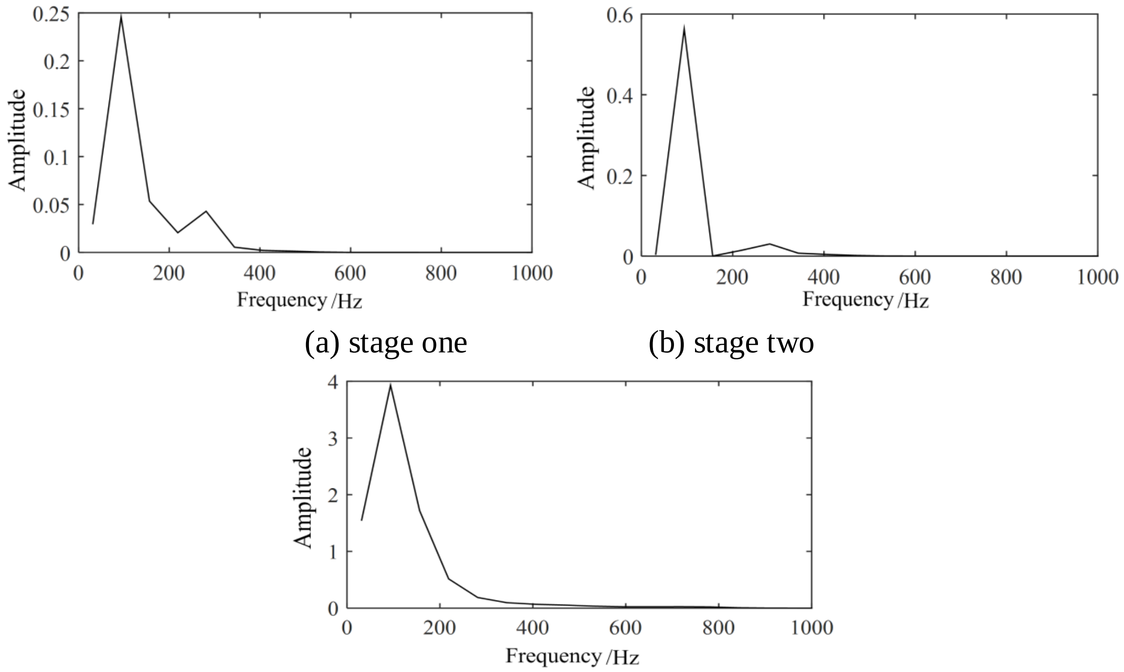


(a) stage one (b) stage two

(c) stage three

Figure 2. Discharge waveform

The insulator leakage current is relatively small during the initial discharge, only a few mA; with the increase of voltage, the insulator leakage current reaches 100mA when the insulator flashover occurs as shown in Figure 3. At the same time, the current waveform is sinusoidal; when the discharge is complete, the current waveform is almost sinusoidal, and when the insulator flashover occurs, the current waveform distorts, and the waveform will be drop to zero suddenly.



(a) stage one (b) stage two

(c) stage three

Figure 3. Hilbert marginal spectrum

Hilbert spectrum is a weighted joint time-frequency amplitude distribution. A certain frequency in the marginal spectrum only represents the possibility of its vibration, and the exact time of the vibration wave in the Hilbert spectrum is given. In the marginal spectrum, A certain frequency value characterizes the presence possibility of a sinusoidal or cosine wave of this frequency component. Figure. 3 shows Hilbert's marginal spectrum. It can be learned that the frequency of discharge in stage 1 and stage 2 ranges from 0 to 150Hz, and from about 200Hz to 250Hz. It is most likely to occur in the fundamental wave 50Hz, and some third harmonics are 150Hz and fifth harmonics are 250Hz. Phase three is concentrated between 0 and 150Hz.

4. Discussion

4.1 The IMF characteristics of different stages of discharge extraction

In this paper, the EMD decomposition of the leakage current signals at different discharge stages is performed. The last component of each graph is the residual component. Moreover, the number of IMF component is variable at different discharge stages. The number of components during the initial discharge phase and flashover are usually 6 to 7, the number of components in the discharge process is generally 3 to 5.

4.2 Different times of discharge leakage current time-frequency entropy

The corresponding time-frequency entropy can be obtained according to the time-frequency entropy calculation formula. The frequency is basically 50Hz in the initial discharge stage and through discharge process. During flashover, the leakage current signal is basically 50Hz before the waveform drops to zero, and after the waveform drops to zero, the frequency also drops to zero, which is consistent with the above waveform and Hilbert marginal spectrum analysis results.

The time-frequency diagram is also classified as 6500 equal areas, at initial discharge, the value of $s(q)$ is 9.3901, that is calculated by the time-frequency entropy formula; during discharge process, the value of $s(q)$ is 8.4602; When the insulator flashover, the value of $s(q)$ is 7.3966.

Table 2. Time-frequency entropy value of insulator discharge three-stage

Leakage current signal	Stage 1	Stage 2	Stage 3
Time-frequency entropy	9.3901	8.4602	7.3966

5. Conclusions

In this paper, HHT method is used to analyze the leakage current signal of porcelain insulators. Three different discharge stages are selected, and the signal is decomposed by EMD first, and then HHT calculation is carried out. The following conclusions are drawn: the frequency distribution of Hilbert spectrum of insulators is in the range of 0-150Hz and 200-250Hz. The component of proper mode function in stage 1 and stage 3 is more than that in stage 2. The time-frequency entropy value of the leakage current data before the insulator flashover is always greater than that after the insulator flashover.

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