Vibration signals denoising method based on wavelet analysis

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Abstract. At present, the application of gas insulated metal enclosed switchgear (GIS) in power system is used more and more widely, but the detection of GIS is often disturbed by various kinds of noise, which affects the effective location of the fault point. Commonly it can not reflect the frequency characteristics of the signal locally for using Fourier denoising method, moreover, it is difficult to meet the requirements of the actual detection. Based on this problem, the system used the soft and hard threshold method to set the threshold value of the vibration signal. And the method of wavelet analysis with multi resolution characteristics was used to reduce the noise effectively. Through the Matlab simulation and the actual test results to verify its accuracy, it proves that denoising method based on wavelet analysis is a suitable way to extract useful signals, improve Signal to Noise Ratio and locating accuracy.

Introduction

Gas insulated metal enclosed switchgear(GIS) is widely used in the field of high voltage transmission because of its small size, good insulation properties and high reliability. But GIS has strong electromagnetic waves and white noise around the equipment, such as thermal noise of equipment, noise in ground grid, dynamic power line of equipment, relay protection circuit and so on, which seriously affect the extraction of flashover characteristic signal[1]. In general, noise is often produced during the generation or transmission of a signal, so we capture the signal that contains noise from the sensors[2]. The addition of noise will seriously affect the quality of the signal, and also increase the difficulty of processing the follow-up signal, which will greatly reduce the timeliness of positioning and accuracy. In general, to eliminate noise interference can use the hardware suppression methods, such as using a variety of filter circuits and shielding measures; and can also use the software processing methods, which use the signal noise separation algorithm to eliminate noise[3-4].

In practical application, signal always contains part of spike or mutation, and the noise is not necessarily stationary white noise. Using the traditional Fourier method to analyze this kind of effect is not obvious, because it does not show a signal change at a point in time[5]. Besides, weak signal that has the obvious changes in a certain time and space will affect the whole spectrum of the signal[6]. The system using wavelet method for reducing the noise of the signal, wavelet analysis is a time and frequency analysis method, can be used to do multi resolution analyze for the signal in time and frequency domain, and can distinguish the abrupt part and the noise in the signal effectively[7-9]. It can be used to extract the transient signal and the waveform characteristic of the extracted signal effectively from the non-stationary vibration signal with different resolutions in the time-frequency plane[10-11]. Here, GIS flashover fault detection system based on wavelet analysis use threshold denoising method that can reduce the white noise and electromagnetic wave in the environment, and greatly improve the Signal to Noise Ratio and accuracy of positioning[12].

Wavelet Analysis Theory

A square integrable function $f(t) \in L^2(R)$ can be regarded as a function of step by step approximation. Each level of approximation with a low-pass smoothing function $\psi(t)$ for $f(t)$ is a stage telescopic result. Doing two level decomposition for a space will produce a group step by step contained subspaces:

$$\ldots,\ V_0 = V_1 \oplus W_1\ ,\ V_1 = V_2 \oplus W_2,\ \ldots,\ V_j = V_{j+1} \oplus W_{j+1},\ \ldots\ j \in [-\infty, +\infty] \quad (1)$$

A smaller j value is a greater space.

The v_j space satisfies representation of the following multiresolution:

$$f_j = f_{j-1} + d_{j-1} = f_{j-2} + d_{j-2} + d_{j-1} = f_M + d_M + d_{M+1} + \cdots d_{j-1} \quad (2)$$

Where,

$$f_l(t) = \sum_{k \in Z} c_k^l \varphi_{l,k}(t) \in V_l,$$

$$d_l(t) = \sum_{k \in Z} d_k^l \psi_{l,k}(t) \in W_l,\ \ l = M, \cdots, j-1 \quad (3)$$

$f_l(t)$ expresses low frequency components of f_j, $d_l(t)$ expresses the high frequency components of f_j.

The orthogonal projection f_j is known in V_j, then $f_l(t)$ and $d_l(t)$ in scale function $\{c_k^j\}$ and wavelet coefficients $\{d_k^j\}$ can be represented by the following formula:

$$f_j(t) = \sum_{k \in Z} c_k^j \varphi_{j,k}(t) = \sum_{k \in Z} c_k^{j-1} \varphi_{j-1,k}(t) + \sum_{k \in Z} d_k^{j-1} \psi_{j-1,k}(t) \quad (4)$$

Hypothesis observed signal is expressed as:

$$y_i = x_i + ez_i \quad (5)$$

In the formula, x_i is a useful signal, e is noise level, z_i is noise signal. The z_i obeys the normal distribution N : （0, σ_π^2）.

Besides, image using the soft threshold method is smoother, but image on the edge may appear distortion; and the hard threshold method has a better marginal local characteristic. Therefore, it is necessary to design a kind of the eclectic method of soft threshold and hard threshold. This method can get approximate optimal estimation of the useful signal, the function expression:

$$f_h(t) = \begin{cases} \operatorname{sgn}(x(t))(|x(t)| - \lambda a) & |x(t)| > a \\ 0 & |x(t)| \le a \end{cases} \quad (6)$$

In the formula, λ is an arbitrary constant, $0 < \lambda \le 1$, through specific denoising effect to determine this value.

Simulation analysis

Firstly, the signal features of white noise were extracted from the GIS simulation equipment. Oscillograph was shown in Figure 1.

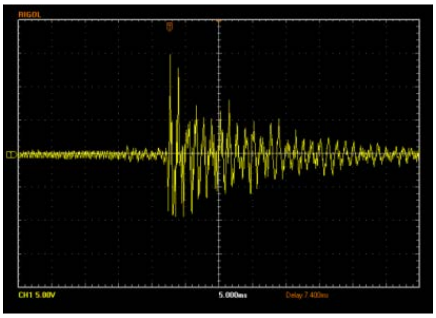

Fig. 1 analog signal acquisition

Then, as could be seen from the extracted signals, the acoustic signal was similar to the oscillator signal. Therefore, a set of mathematical model was established in the experimental process, namely exponential decay model.

Single exponential decay model:

$$f(t) = a_1^{-t/T_1} \sin(f_c \times 2\pi t) \tag{7}$$

Double exponential decay oscillator model:

$$f(t) = a_2 (e^{-2.2t/T_2} - e^{-1.3t/T_3}) \sin(f_c \times 2\pi t) \tag{8}$$

In the formula, a_1 and a_2 are the amplitude of discharge signal, T_1、T_2 and T_3 are the decay time of the signal, f_c is oscillation frequency of the signal .

Simulation experiments used the combination of two models in the formula. By MATLAB7.10 simulation experiment, the parameters were set for the $f_c = 5 \times 10^5 Hz$, $f_s = 1 \times 10^7 Hz$, as shown in Figure 2.

In the simulation signal by adding the noise of a certain Signal to Noise Ratio, as shown in Figure 3.

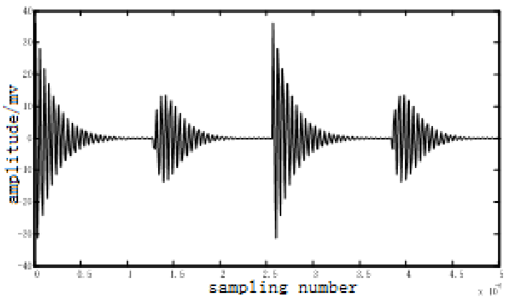

Fig. 2 simulation signal

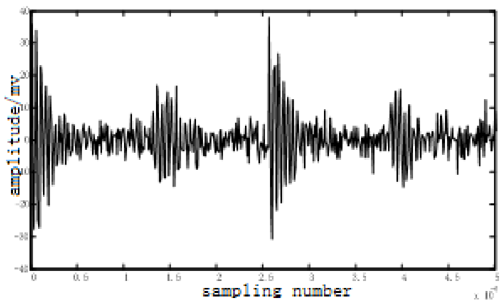

Fig. 3 simulation signal with noise

In the experiment, the correlation were introduced to judge the quality of signal processed.

The coif wavelet system using soft and hard threshold method, selecting different wavelet functions and decomposition levels, got the correlation coefficient table, as shown in table 1. From the table 1 can be seen, when decomposition layer is 6, wavelet function is coif5, correlation coefficient is the biggest, and the corresponding value is 0.8931. Denoising effect is the best.

Table 1 the correlation coefficient of coif wavelet using soft and hard threshold denoising method

	coif1	coif2	coif3	coif4	coif5
1	0.8130	0.8480	0.8705	0.8823	0.8924
2	0.7712	0.8038	0.8311	0.8413	0.8507
3	0.7916	0.8281	0.8536	0.8642	0.8713
4	0.8010	0.8379	0.8638	0.8650	0.8815
5	0.8076	0.8475	0.8745	0.8836	0.8895
6	0.8089	0.8497	0.8771	0.8869	0.8931
7	0.8089	0.8503	0.8774	0.8865	0.8925

This scheme uses coif5 wavelet that decomposition layer is 6. simulation result is shown in Figure 4.

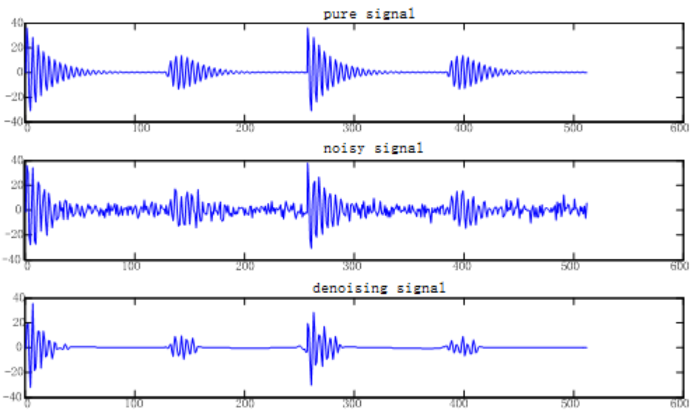

Fig. 4 simulation signal processing

Test results

The sensors are stuck in the middle of the outer wall of the air chamber, and then the same position of the wall is struck, and the position of the sound box is continuously moved, as shown in Figure 5. In the course of the experiment, the knocked position is shown in Figure 6.

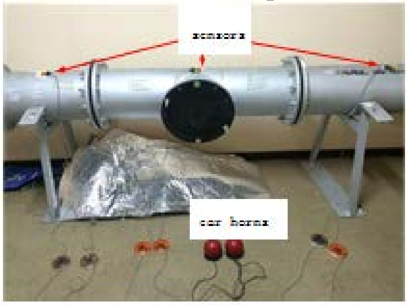

Fig. 5 experimental platform

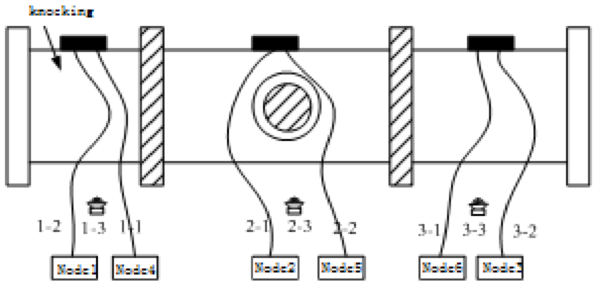

Fig.6 schematic diagram of the test platform.

First determine the location of a hit, as shown in Figure 6. In a quiet environment, using the equipment without adding wavelet algorithm (Node1,Node2,Node3) carries out three tests, the test data is shown in Table 2.

Table 2 test data before adding noise

Sequence number	Node 1	Node 2	Node 3
1	958	730	318
2	756	346	–
3	902	687	358

Then, according to the sequence of the sound box in Figure 6, it is placed(The speaker is placed in one of the locations at each test.), and then hit three times in each position, finally two sets of test data are recorded, which are shown in Table 3 and table 4.

Table3 Using wavelet analysis before the test results Table4 Test results by using the method of wavelet analysis

Speaker position	Node 1	Node 2	Node 3
1#1	1636	1224	544
1#2	1422	1357	672
1#3	1484	1383	563
2#1	1936	2043	621
2#2	1926	1861	431
2#3	1513	1322	800
3#1	1523	1250	1311
3#2	1663	1378	1193
3#3	1499	1032	1096

Speaker position	Node 4	Node 5	Node 6
1#1	1012	700	232
1#2	857	662	–
1#3	826	673	201
2#1	936	755	332
2#2	910	635	267
2#3	892	621	349
3#1	893	696	258
3#2	758	401	–
3#3	830	423	211

From table 3 that when the sound box is placed on the 1# position, the data of No. 1 node and No. 2 node vary little; when the sound box is placed on the 2# position, sometimes the data of No. 2 node are slightly greater than the data of No. 1 node, and the data of No. 1 and No. 2 node are basically similar; when the sound box is placed on the 3# position, the signal data of No. 2 and No. 3 node basically have not difference, which obviously no longer meet the law of attenuation. And the data in table 4 are basically in accordance with the data characteristics of table 2, which illustrates that basically meets attenuation characteristics of the signal in the GIS equipment. Some of the data also exist certain deviations, maybe due to the existence of differences among equipment lead to deviations of the data. This shows that the noise in the environment will affect the accuracy of positioning in some cases. And after joining the wavelet analysis algorithm, through the comparison between the experimental data, we can still find out the position of flashover, and can basically be able to respond to the strength of the signal.

Conclusion

The results of simulation and experiment show that denoising method based on wavelet analysis is a superior method to extract the useful signal, remove the noise and reflect the mutation signal, which has very wide application prospect and practical value. In the detection of gas insulated metal enclosed switchgear, the traditional signal denoising method has been unable to feed usually requires, where, in this paper, the wavelet denoising method is suitable for detecting stationary target signal with the transient abnormal phenomena. What's more, it retains the variational components, and can completely extract the feature of the part signal, and greatly improves the signal-to-noise ratio of the system and accuracy and timeliness of the detection.

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