Simulation Research on Transformer Pre-test High Voltage Electrical Insulation Parameters

Minhu Xu*, Yun Guo, Kexin Zhang, Hang Zhang, Yubo Shen and Xiangyu Zhao
State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute, Harbin 150040, China

*Corresponding author email: minhu_xu@sgcc.com.cn

Abstract. This article uses an image processing method to study the hydrophobicity of transformer composite insulators, and then determine the surface aging performance of transformer composite insulators. In order to meet the requirements of the randomness and ambiguity of the hydrophobic image, this paper uses a series of algorithms to process the hydrophobic image of the composite insulator: the enhancement of the hydrophobic image based on adaptive histogram equalization, the hydrophobic image based on wavelet transform filtering and segmentation of the hydrophobic grade classification of composite insulators. Taking characteristic parameters such as the largest water droplet shape factor and area ratio as input, and the surface insulation aging performance of composite insulators as output, the relationship between insulation parameters and insulation aging performance is established. The simulation results show that the method can judge the surface insulation aging performance of composite insulators into three states: good, normal, and bad. Especially when the maximum water drop area ratio is input, the classification accuracy rate reaches 93.3%.

Key words. Transformer composite insulator, hydrophobicity, simulation analysis, wavelet transform, electrical insulation parameters.

1. Introduction
As the hub equipment of the power system, power transformers play a vital role in the operation of the power grid. The overall life of a transformer mainly depends on the life of its insulating material, so the effective determination of the aging state of the transformer’s insulation system has long received extensive attention. The current methods for monitoring the aging state of transformer insulation mainly include conventional preventive tests and some unconventional tests. The conventional tests mainly include the measurement and analysis of characteristic quantities such as electrical insulation parameters, dissolved gases in oil, polymerization degree, furfural, micro water, partial discharge, etc., while the unconventional methods mainly refer to the dielectric response method, which analyses the insulation material Polarization phenomenon judges its insulation status [1]. This paper uses image processing technology to study the method of judging the surface insulation aging performance of composite insulators. Because the surface aging performance of composite insulators is closely related
to the hydrophobicity of composite insulators, we choose to study the surface aging performance of composite insulators by studying the hydrophobicity of composite insulators.

2. Hydrophobic image filtering based on Haar wavelet transform

In the process of collection, transmission, storage, etc., hydrophobic images of insulators are easily affected by external environment such as light, electromagnetic fields, and generate noise, such as dotted noise, which leads to a decrease in the quality of hydrophobic images, and noise-containing images are used for subsequent segmentation. The processing causes great trouble, for this reason, it is necessary to perform certain filtering and denoising processing to remove the noise signal while retaining the useful image signal. It is known from relevant literature that the processing of hydrophobic image noise mainly deals with its high-frequency coefficients [2]. Therefore, as long as the relevant algorithms are used to separate the high-frequency coefficients from the image and perform corresponding processing, the purpose of denoising is achieved and a good foundation is laid for the subsequent segmentation.

The Haar wavelet transform is faster than other wavelet transforms because its Haar function is relatively simpler, and the constructed filter has linear phase. This paper uses Haar wavelet transform to perform wavelet decomposition, extract low-frequency and high-frequency coefficients respectively, filter on the basis of high-frequency coefficients, and then reconstruct the processed high-frequency coefficients and low-frequency coefficients to achieve hydrophobic image filtering and segmentation. Lay the foundation [3]. When the French mathematician A. Haar first proposed the orthonormal wavelet basis, Point out that the function family function can represent an orthonormal basis of the function space \( H^2(R) \), and define the function family expression as:

\[
\{2^{-m/2} \psi(2^{-m} x - n), m, n \in \mathbb{Z}\}
\]

(1)

In wavelet analysis, the composition of a vector space can be represented by a scale function or a wavelet function. The vector space based on the scale function is \( V^j \), and the vector space based on the wavelet function is \( W^j \). The expressions are respectively for:

\[
V^j = sp\{2^j/2 \phi(2^j x - i)\}, i = 0,1,\cdots,(2^j - 1)
\]

(2)

\[
W^j = sp\{2^j/2 \psi(2^j x - i)\}, i = 0,1,\cdots,(2^j - 1)
\]

(3)

In the formula: \( j \) is the scale factor of the function, that is, \( j \) controls the zoom or enlargement of the graph; \( i \) is the translation factor, and the function is shifted to the \( x \) axis by changing \( i \). \( 2^{j/2} \) is the normalized Haar basis. Then the vector space \( W^j \) generated by Haar wavelet \( \psi^j(x) \) is included in the vector space \( V^{j+1} \). The vector spaces \( V^j \) and \( W^j \) generated by Haar basis functions \( \phi^j(x) \) and Haar wavelet \( \psi^j(x) \) have the following properties:

\[
V^{j+1} = V^j \oplus W^j
\]

(4)

In the vector space \( V^{j+1} \), each function in the \( W^j \) vector space and each function in the \( V^j \) vector space are orthogonal. The basic idea of wavelet transform is to use a series of functions of scaling and translation to express the function or signal in the Fourier transform. Fourier transform can provide information in the frequency domain, but there is a problem of local information loss in time; while wavelet transform can not only obtain the time information of the signal to be analysed through the translation function, but also obtain the frequency domain information of the signal to be analysed.
through the zoom function [4]. The essence of image filtering is based on the difference in the distribution of noise energy and image energy in the frequency domain. In the process of wavelet transformation, the signal to be analysed is decomposed into low-frequency and high-frequency components. The low-frequency component is the main area of the image energy distribution, and the high-frequency component is noise energy and image detail energy are mainly distributed areas, so the effect of filtering depends on the processing of high-frequency components. High-frequency components cannot be completely removed. Instead, certain noise and image details should be retained.

The hydrophobic image of the silicone rubber insulator has a certain particularity, because its surface contains water droplets, pollution, etc., and the image acquisition process is easily affected by the external environment and generates noise, so it needs to be filtered. In this paper, Haar wavelet is used to decompose it into high-frequency and low-frequency coefficients, and the processing is performed on the basis of the respective coefficients. The processed new coefficients are reconstructed by inverse wavelet transform to achieve the purpose of filtering. The following figure 1 is the decomposition and reconstruction Basic block diagram.

![Wavelet Decomposition and Reconstruction Diagram](image)

**Figure 1. Basic block diagram of wavelet decomposition and reconstruction**

In the process of decomposition and filtering of hydrophobic images, high-frequency coefficients are mainly processed, while certain compensation can be used for uneven illumination noise. This article only deals with high-frequency coefficients and selects a threshold and a corresponding threshold function pair High-frequency processing, and then obtain new high-frequency coefficients, and finally reconstruct the denoised hydrophobic image [5]. The decomposition expression of image $f_j$ by Haar wavelet transform decomposition method is as follows:

$$f_j = a_j - 1 + \cdots + a_{j-1} + f_{j-1} + \cdots + a_0 + f_0$$

The expressions of $a_{j-1}, f_{j-1}$ are:

$$a_{j-1} = \sum_{l \in \mathbb{Z}} b_{j-1} \psi(2^{j-1} x - l)$$

$$f_{j-1} = \sum_{l \in \mathbb{Z}} a_{j-1} \phi(2^{j-1} x - l)$$

After the signal $f_j$ is decomposed, it is actually convenient to process it, and the purpose of processing is nothing more than two. One is to filter out noise, thereby discarding the noise
component $W_j$. The remaining signal naturally contains less noise; the other is to correct The signal is compressed, the smaller amplitude of the noise component $W_j$ can be discarded, and the discarded part has little effect on the original signal, only the larger amplitude noise component $W_j$ is transmitted, and finally a larger compression can be obtained ratio. After signal decomposition, the following expression can be obtained:

$$f_j(x) = \sum_{j=0}^{J-1} \sum_{k \in \mathbb{Z}} h_j \varphi (2^j x - k) + \sum_{k \in \mathbb{Z}} a_j^0 \phi (x - k)$$  \hspace{1cm} (8)$$

According to formula (8), it can be seen that if the wavelet coefficient $b_j^k$ is modified, the processing signal can be filtered. This article is to filter the high-frequency signal, so a threshold $\delta$ is set. When the threshold is small, although more detailed information can be retained, the noise removal effect is not ideal, and when the threshold is too large, most of the noise is filtered out at the same time, the important details are filtered out as noise, and the reconstructed image will inevitably become blurred. Therefore, the choice of threshold is more important. After processing the high and low frequency coefficients, it is necessary to perform inverse wavelet transform to finally achieve the purpose of reconstruction. Haar reconstruction theorem:

$$f = f_0 + \alpha_0 + \alpha_1 + \cdots + \alpha_{J-1}$$ \hspace{1cm} (9)$$

To reconstruct the signal of formula (9), the expression is obtained as:

$$f_j = \sum_{k \in \mathbb{Z}} a_j^k \phi (2^j x - k)$$ \hspace{1cm} (10)$$

After using Haar wavelet to decompose and reconstruct the hydrophobic image, the result is shown in Figure 2. It can be seen from the figure that the background (silicone rubber layer) of the hydrophobic image as a whole becomes dim, causing water droplets and silicone rubber layer the layering between is clearer, and while the high frequency coefficients are denoised, the edge contours of the water droplets become a little fuzzy [6]. The image processed by wavelet is of vital importance to the extraction of water droplet information feature (segmentation processing) in the next step.

![Figure 2](image-url)  
(A) Original image    (B) The reconstructed image

**Figure 2.** This article uses methods to reconstruct

### 3. Experimental analysis

#### 3.1. Performance division

The hydrophobicity of composite insulators is divided into seven grades of HC1-HC7. According to IEC/TS62073-2003, the HC grade is named WC grade, and the corresponding grades are completely
consistent. WC1-WC2 is specified as a hydrophobic state, and WC3-WC5 is defined as an intermediate transition state, and WC6-WC7 is defined as a hydrophilic state. According to these three states, the insulation performance of the composite insulator silicone rubber material can be divided into good, normal and poor. After the image is obtained, it is segmented and binarized. Figure 3 shows the binary images corresponding to the three types of samples with different performance.

3.2. Parameter selection
Tokoro T of Japan proposed the shape factor method to determine the level of hydrophobicity. The shape factor $f_c$ is defined as follows:

$$f_c = \frac{4\pi a}{c^2}$$  \hspace{1cm} (11)

In the formula, $a$ is the area of the largest water droplet, and $c$ is the circumference of the largest water droplet. The paper proposes that the ratio of the largest water droplet area to the total area $k$ is used as one of the composite insulator image characteristics, which is calculated as follows:

$$k = \frac{a}{s}$$  \hspace{1cm} (12)

In the formula, $a$ is the area of the largest water drop, $s$ is the entire image area, so this article will use $f_c$ and $k$ two features as input parameters to analyse the surface insulation performance of silicone rubber insulators.

3.3. Result analysis
This paper takes 63 samples as the research object, 33 sample data as training data, and 30 sample data as test data. The classification results are shown in Figure 4 and Figure 4. Among the three parameters as the input of the support vector machine, the classification accuracy rate of the largest droplet or water trace alone is the highest, reaching 933%. The maximum area ratio and shape factor as the input accuracy rate is only 86.7%, because there is a certain correlation between the two parameters, which reduces the accuracy of classification, and multiple feature parameters increase the complexity of SVM classification [7]. It shows that SVM classification is not necessarily better because the more input feature parameters, so the maximum water drop or water trace ratio can be used to judge the insulation performance of composite insulator silicone rubber.
4. Conclusion

Noise is inevitably introduced in the process of acquiring the hydrophobic image of transformer composite insulators. The noise mainly exists in the high-frequency coefficients. The paper uses Haar wavelet to decompose the electrical insulation parameters into high-frequency and low-frequency coefficients, and noises on the high and low-frequency coefficients. Although the processed image becomes darker overall, the layering between the target (water droplets or water marks) and the background (silicone rubber layer) is more obvious. Use the adaptive segmentation method of maximum inter-variance to segment the processed image. The segmentation results show that if the noise can be better processed, a better segmentation effect can be achieved.

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