Transmission line insulator fault detection based on ultrasonic technology

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Abstract. With the continuous development of modern society, the construction of transmission network has been rapidly advanced, and the reliability of power supply has been fundamentally improved, but the workload of detecting insulators has also increased. In order to further reduce the tripping rate of the transmission line, the insulator fault detection work cannot be delayed. However, the traditional detection method has low efficiency, poor safety and high cost, which cannot meet the requirements. This paper proposes a method of applying ultrasonic technology to line insulator detection by referring to the application of ultrasonic technology in the United States and South Korea. The method realizes fault detection of the insulator by collecting, processing and amplifying the ultrasonic signal.

1. Introduction

At present, there are many methods for measuring the insulation of the transmission line, including two types of contact measurement and non-contact measurement. Contact measurement mainly uses a contact instrument to measure physical quantities such as voltage, current, and insulation resistance. The most widely used non-contact measurement is temperature measurement, such as infrared sub-imager. Due to cracking of the insulator, damage to the tree, damage to the insulation, and other faults, the method of judging the fault point by temperature measurement is hardly found [1].

Insulator detection is mainly used by artificial climbing towers, which is dangerous and time consuming. Through the understanding of insulator faults, finding the most effective detection method for insulator faults will be of great significance to the safe operation of the entire grid. If there is an instrument, it can patrol the high-voltage transmission line insulators and power supply equipment for long distances, predict potential faults, and detect the operation status of the insulators through long-distance and continuous power, avoiding one-on-one inspection, blindly overhauling and wiping the insulators. It can save a lot of manpower and material resources, and can also improve the health of equipment.

The ultrasonic detecting method uses an ultrasonic sensor to detect a signal generated when a partial discharge of a deteriorated insulator occurs, and the sound wave and the ultrasonic wave emitted from the insulator are used to determine the deterioration degree. The instrument can transmit the laser beam at a long distance to lock the target to be measured. Due to the unique transmission characteristics of the ultrasonic wave, it is not easily affected by the environment and the weather. It is the most effective method for detecting various faults of the insulator at a long distance. Because the method can be carried out at a long distance and charged, it is safe, reliable and efficient, and the
application of this method for detecting insulators can greatly save the operation and maintenance cost of the line [2].

2. Current status of ultrasonic technology application at home and abroad

Ultrasonic testing is a comprehensive technology that includes many disciplines based on physics, electronics, mechanics and materials science. It is widely used in many fields such as industry, medical equipment and marine detection. Ultrasonic testing is a type of non-destructive testing, that is, the use of ultrasonic waves to detect the current state of a workpiece or device. From the end of the 19th century to the beginning of the 20th century, after the piezoelectric effect and the anti-piezoelectric effect were discovered in physics, the method of generating ultrasonic waves by using electronic technology was solved. Ultrasound has been widely used in flaw detection, medical treatment, ultrasonic inspection, and measurement. In terms of distance, in recent years, it has also been applied in power detection.

The United States and South Korea first applied ultrasonic testing technology to the detection of defects in power equipment, and achieved significant gains in the ultrasonic field. It was determined that ultrasonic equipment would generate ultrasonic waves when discharge, flashover, and breakdown occurred [3]. The frequency range of the ultrasonic wave is 35 kHz - 40 kHz. Due to the different equipment, the frequency of the transmission is slightly different, but it is basically within this range. Therefore, after research and experiment, the corresponding ultrasonic sensor has been developed to solve the problem of signal acquisition. After several years of continuous improvement and development, it has achieved good results in the United States and South Korea, especially in Korea, which has been applied extensively and played a major role [4].

3. Common methods and disadvantages of transmission line insulator detection

3.1 Direct observation

The most common method for physical structural defects outside the insulator is the direct observation method, which uses direct observation of the insulator with optical instruments such as binoculars or by means of a telescope to find various common surface defects such as insulating sheaths, umbrella groups, fittings, etc. There is no damage to the parts. However, the direct observation method is not reliable enough and is not accurate enough. Sometimes it is necessary to check the tower and it is impossible to know the internal fault of the insulator [5].

3.2 Distributed voltage measurement

The main feature of the deteriorated insulator is that the insulation resistance is lowered, resulting in a low or even zero sharing voltage. Using this feature, the insulator resistance state can be known by comparison with the standard voltage distribution of the normal insulator string. However, this method requires live contact measurement and needs to be tested under good weather conditions.

3.3 AC withstand voltage method

This method judges the resistance state of the insulator by using the deteriorated insulation performance of the insulator and the reduction of the withstand voltage level. This method is the most intuitive and authoritative reference method for testing the effectiveness of other methods. However, this method cannot be measured on site in the field, and the tested insulator needs to be taken off and taken to a special test site.

3.4 Ultraviolet imaging

A small but relatively stable surface partial discharge can result in carbonized channels or electrical erosion of the composite insulator shed and jacket. When the surface of the composite insulator forms a carbonization channel, its service life is greatly reduced, even in the short-term insulation breakdown. The electronic ultraviolet optical detector can be used to electrically detect the carbonization channel
formed on the surface of the composite insulator due to partial discharge and the ultraviolet light emitted by the charged particles in the electrical erosion. Partial discharge occurs when a conductive carbonization channel is formed on the surface of the composite insulator. This method is used to detect the partial discharge of the composite insulator, and it is required to be tested at night and in a normal temperature environment, and the effect is better when the detection is performed in an environment with high humidity or even rainfall. However, the test results are easily misjudged by the observation angle, and the detection equipment is also relatively expensive, and cannot be equipped with a large number of transmission line operation and maintenance departments. Therefore, the inspection work cannot be carried out according to the regulations [6].

4. Transmission line insulator fault detection based on ultrasonic technology

4.1 Analysis of application principle of ultrasonic technology
It can be known from the insulator discharge mechanism that no acoustic signal is emitted when the insulator is not discharged. With the development of the discharge program, the discharge is gradually enhanced, and the sound wave emission signal is from nothing, from weak to strong. The sound wave signal can be regarded as a point sound source and propagates to the surroundings in the form of a spherical wave in the air medium [7]. Since the energy of the acoustic signal is part of the energy released by the discharge, there must be a quantitative relationship between the energy of the acoustic signal and the energy of the discharge. A large number of ultrasonic waves will occur when the power line insulators are exploding. Such ultrasonic waves are inaudible to the human ear, the human ear audible frequency is below 20 kHz, and the ultrasonic frequency is between 20 kHz and 200 kHz [8].

4.2 Technical method for detecting insulators of transmission lines by ultrasonic technology

4.2.1 Ultrasonic signal acquisition
The ultrasonic signal can be realized by the wave concentrator, so that more ultrasonic waves are reflected by the interface and concentrated, and received by the ultrasonic sensor, so that more ultrasonic high-frequency signals can be obtained.

Insulator failure Partial discharge phenomena are accompanied by the generation and emission of ultrasonic waves, and the frequency of the ultrasonic signals emitted is concentrated between 20-40 kHz and 80-140 kHz. In technical applications, two different types of ultrasonic sensors can be used to receive ultrasonic signals in two frequency bands.

4.2.2 Ultrasonic signal band selection and filtering
Experiments have shown that insulators produce a very broad continuous spectrum at the time of discharge, with frequencies ranging from a few hertz to hundreds of thousands of hertz. When the sound wave propagates in the medium, as the propagation distance increases, the energy gradually decays, and the attenuation law of sound pressure and sound intensity is:

\[ P_x = P_0 e^{-\alpha x} \]  
\[ I_x = I_0 e^{-2\alpha x} \]

Where: \( P_0 \), \( I_0 \) respectively refers to the sound pressure and sound intensity of the sound source; \( P_x \), \( I_x \) respectively refers to the sound pressure and sound intensity from the sound source \( x \); \( x \) refers to the distance between the sound wave and the sound source; \( \alpha \) is the attenuation coefficient, the unit is Np/m.

The fault insulator test in the laboratory shows that the sound wave in the 25-60 kHz band is the strongest when the insulator has the same intensity current leakage; the same is true when the insulator current leakage changes.
Through many experiments at the engineering site, it was finally confirmed that it is best to select the ultrasonic signal of 40 kHz for analysis, which can be used as the center frequency of ultrasonic signal acquisition.

4.2.3 Amplification of ultrasonic signals
The acquired signal needs to be amplified, but it is found that the amplified signal is easily distorted. Finally, through the multi-stage precision amplification of the front, middle and rear, and AD conversion is placed in the second-stage amplification, the audio output is placed in the three-stage amplification, which not only ensures the signal amplification without distortion, but also ensures the reliability of the output.

The acquired ultrasonic signal is first amplified by the amplifier circuit built in the host computer, and then the signal of the useful frequency segment is selected by the band pass filter circuit to be analyzed and judged by the host circuit, and the ultrasonic signal is filtered before and after as shown in Figure 1.

![Figure 1. Ultrasonic signal diagram before and after filtering](image)

The host circuit is a signal analysis judgment composed of a single trigger and an overall control circuit. The workflow is shown in Figure 2.

![Figure 2. Working flow chart of the host circuit](image)
4.2.4 Host hardware and software design
The ultrasonic online diagnostic system software realizes real-time analysis and intelligent diagnosis of data in the field data collection. After the main device completes the detection work, the front-end data may be imported into the ultrasonic online diagnostic analysis system. The system will read and transfer the data, and automatically and intelligently analyze the data; then the system reads the data into the analysis software. Reprocessing to facilitate analysis of the map.
Through the hardware and analysis software, the ultrasonic signal is finally audibly converted, as shown in Figure 3.

![Listening conversion process](Image)

**Figure 3. Listening conversion process**

4.2.5 Ultrasonic probe design
Ultrasonic probes can be divided into piezoelectric type, magnetostrictive type, electromagnetic type according to their working principle, and piezoelectric type is most commonly used. Piezoelectric ultrasonic waves are piezoelectric oscillators that generate a free-running signal after voltage is applied.

Using the design of the dual-probe collector, the acquisition of ultrasonic signals in different frequency bands can enhance the intensity and sensitivity of the detection. The ultrasonic sensor is integrated with the preamplifier. It is necessary to pay attention to the factors of signal interference: one is the interference of the electric field on the piezoelectric ceramic; the other is the influence on the amplifying element. The frequency of the power frequency electric field is low, the effect of the magnetic field can be neglected, and the method of electrostatic shielding is used to prevent interference.

5. Application case
Successfully researched and developed the software for the ultrasonic portable detection device, which has a good effect in the practical application of the Dandong site. The following is a case application of Dandong Power Supply Company:

![Dandong power supply line insulator real map](Image)

**Figure 4. Dandong power supply line insulator real map**

6. Conclusion
The ultrasonic detection technology that has emerged in recent years can analyze and test substation equipment and transmission equipment. This technology is enabled in the power grid maintenance process to quickly detect defects existing in the power equipment without power failure, and then determine the defect level and specific location based on the spectrum analysis. New technologies make defect detection more flexible. Inspection efficiency and personnel safety have been greatly improved.

Through on-site and laboratory research and application, we can basically derive three types of typical insulator ultrasonic maps. These maps are important for implementing on-line detection of
insulators, quickly locating, and determining the type of fault. Fig. 5 is an ultrasonic waveform emitted by a good insulator, which is characterized by uniform waveform, small amplitude, and almost uniform wave peak. Fig. 6 is an ultrasonic waveform emitted by an insulator at a critical value, characterized in which the waveform is dense, the local amplitude is large, the peak value is uneven, and the local waveform is obviously oscillated. Fig. 7 is an ultrasonic waveform emitted by an insulator having a value of zero, which is characterized by dense waveforms, large amplitudes, and large and uniform peaks.

References
[1] L.M. Wang. On-line detection and analysis of leakage signal of faulty high voltage insulator. Southeast University, (2005)
[2] P. Nie, X.Z. Zhao, Y. Zhang, J.F. Bai. Development of On-line Monitoring System for Insulation of High Voltage Electrical Equipment. Journal of Northeast Electric Power University, 01 (2000)
[3] Z.D. Jia, W. Zhang. Foreign body caused flashover on composite insulator in wet and contaminated condition. High Voltage Engineering, 8, 36 (2010)
[4] Z.Y. Wang, Q. Wang, Research on the AC electric-field distribution along contaminated polymer insulators. High Voltage Apparatus, 4,6 (2010)
[5] Y.C. Cheng, C.W. Li, X.J. Shen, R.H. Chen, Comparison of Several Methods for Detection of Composite Insulators. High Voltage Engineering, 06 (2004)
[6] Ampol Tungkanawanich, Zen-Ichiro Kawasaki, et al. Ground Fault Discrimination based on Wavelet Transform using Artificial Neural Networks. T.IEE Japan, 10 (2000)
[7] C.Z. Xie, Z.W. Du. Analysis of Operational Characteristics of Composite Insulators under Serious Contamination Conditions. High Voltage Engineering, 07 (2004)
[8] J.F. Li, B.S. Li, S.T. Zhao. A measuring method for transmission line sag based on computer vision. Sustainable Power Generation and Supply Conference Provisional Proceedings. Nanjing, China: UK-China Network of Clean Energy Research, (2009)