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ZERO VALUE DETECTION TECHNOLOGY FOR CERAMIC INSULATORS BASED ON CURRENT RESPONSE CHARACTERISTICS UNDER HIGH VOLTAGE IMPACT

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Abstract: Ceramic insulators may experience a decrease in internal insulation performance and become zero value insulators due to environmental factors after being put into operation. Regular zero value testing is required to identify zero value insulators. The impulse high voltage method is one of the effective methods for zero value detection, but existing impulse high voltage methods only focus on the voltage response characteristics of insulators under impulse high voltage, without paying attention to the current response characteristics. This study proposes a zero value detection method based on the current response characteristics under impulse high voltage. The response current is converted into an induced voltage signal through a magnetic ring inductor, and the difference between zero value and the peak induced voltage of a normal insulator is used to achieve reliable identification of zero value. In the case of insulator surface contamination, this method is more robust and has a lower risk of misjudgment compared to detection methods based on voltage response characteristics. The research provides new ideas for insulation testing of ceramic insulators, which helps to improve the reliability of the power grid. Further exploration is needed in the future to determine the reasons for the reliability differences between the two methods.
Keywords: Ceramic insulators; Zero value; Testing; Impact high pressure; Current response characteristics

1 INTRODUCTION

As critical components for insulation and mechanical support in power transmission lines, porcelain insulators may experience degradation of internal insulation performance during long-term operation due to manufacturing defects or mechanical damage, resulting in the formation of "zero-value insulators" [1]. The presence of zero-value insulators significantly reduces the overall insulation effectiveness of insulator strings, induces local electric field distortion, and under adverse weather conditions may lead to line tripping or even large-scale power outages[2]. Therefore, identifying and troubleshooting zero-value insulators remains a crucial task in the operation and maintenance of power transmission lines.

Current zero-value detection methods for porcelain insulators primarily include distributed voltage measurement [3-4], insulation resistance testing [5], infrared/ultraviolet imaging [6-7], electric field analysis [8-11], and impulse high-voltage testing [12-16]. The distributed voltage method, which requires manual tower access to measure voltage distribution, is highly susceptible to environmental interference and demands strict operator safety protocols. While insulation resistance testing evaluates insulation status through DC resistance measurements, studies and practical applications reveal that resistance levels alone cannot fully indicate zero-value defects. Infrared/ultraviolet imaging methods remain vulnerable to environmental temperature and light interference, and shows limited sensitivity for completely penetrated zero-value insulators. Electric field analysis detects zero-value defects by measuring electrical field distortion around insulators, but its effectiveness is influenced by string configuration, environmental humidity, and measurement distance. In contrast, impulse high-voltage testing has emerged as a research hotspot due to its non-contact operation, rapid response, and sensitivity to high-resistance defects. This method applies transient high-voltage pulses to insulators, utilizing their electrical response characteristics under stress to determine the integrity of internal insulation.

Researchers including CHU W, WEN L, and MAO X have conducted studies on identifying zero-value insulators using impulse high-voltage detection methods. Their findings revealed that normal insulators exhibit high response voltages under impulse high-voltage conditions. In contrast, zero-value insulators demonstrate extremely low voltage withstand capabilities under such conditions. While these studies primarily focused on identifying zero-value insulators through voltage response characteristics under impulse high-voltage, current response characteristics were not addressed. In reality, the current response characteristics of insulating media under impulse high-voltage are equally critical, as parameters like response current amplitude are closely related to internal insulation conditions.

In light of this, the study aims to investigate zero-value detection technology based on insulator current response characteristics under impulse high voltage. It explores the feasibility of using current response-related criteria to identify zero-value insulators, while comparing the detection reliability of this method with voltage response-based detection techniques under operational conditions such as contamination accumulation.

2 METHODOLOGY

The most widely used porcelain insulators in overhead high-voltage transmission lines are disc suspension porcelain insulators, making the research focus primarily on zero-value detection for these insulators. The design includes the impulse high-voltage generator circuit and measurement circuit shown in Figure 1. The impulse high-voltage generator circuit boosts 12V power supply voltage to 400V through a DC voltage conversion circuit and zero-voltage switching circuit to charge the capacitor. The charged capacitor rapidly discharges under high-voltage switch control, with the discharge voltage amplified by a high-frequency transformer to generate a microsecond-level impulse high-voltage peak of 60kV, which is applied across the test insulator to form a detection circuit. The measurement circuit consists of a magnetic ring inductor mounted on the detection circuit and an RC acquisition circuit. The magnetic ring inductor converts the current signal in the detection circuit into a voltage signal, while the RC acquisition circuit delays the voltage signal's decay to ensure reliable sampling of instantaneous voltage. The voltage sampling frequency in the measurement circuit is 10kHz.

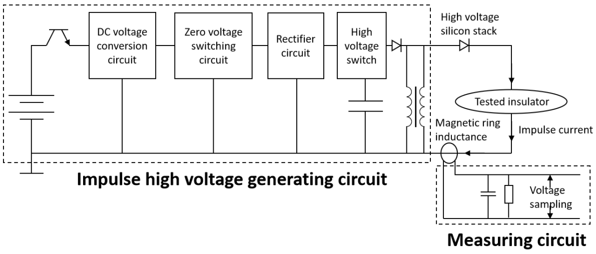

Figure 1 Schematic Diagram of the Circuit for Generating High Voltage Impact and the Measurement Circuit

Based on the aforementioned circuit, when a microsecond-level impulse high voltage is applied to the test insulator, a response current I is instantaneously generated in the detection loop formed by the test insulator and the high-voltage generation circuit. Under the influence of this varying response current, an induced voltage U is generated in the magnetic ring inductor.

3 TEST RESULTS

3.1 Normal and Zero Value Insulator Detection

Based on the above circuit and test method, the detection of normal and zero value insulators with different tonnage was carried out respectively, and the voltage-time curves collected were shown in Figure 2 and Figure 3 respectively.

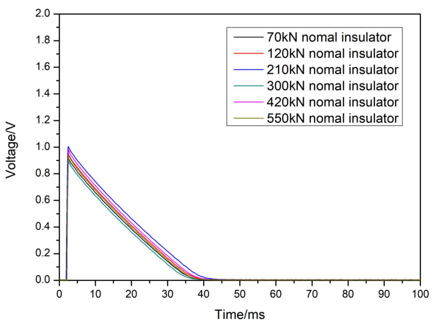

Figure 2 Voltage Time Curve of Normal Insulator

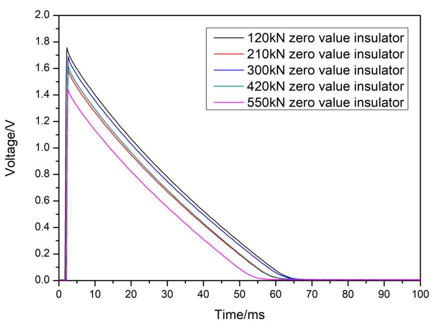

Figure 3 Voltage Time Curve of Zero Value Insulator

As shown in Figures 2 and 3, the collected voltage exhibits two distinct phases of rise and fall. During the voltage rise phase in Figures 2 and 3, the peak voltages of multiple normal insulators with different tonnage values show remarkable similarity, clustering around the 0.9V~1.0V range. Similarly, the peak voltages of multiple zero-value insulators with varying tonnage values demonstrate comparable proximity, concentrated within the 1.5V~1.8V range. This significant difference indicates that when 60kV impulse high voltage is applied across normal and zero-value insulators, distinct response currents emerge in the detection circuit. Normal insulators exhibit smaller response currents, generating induced voltage peaks of approximately 1.0V, while zero-value insulators demonstrate larger response currents, producing induced voltage peaks exceeding 1.5V. This fundamental distinction allows for accurate differentiation between normal and zero-value insulators.

3.2 Comparative Analysis with Voltage-Response-Based Detection Methods

3.2.1 Technical principles and test results of detection method based on voltage response characteristics

The designed detection circuit based on voltage response characteristics is shown in Figure 4. The impulse high-voltage generation circuit is the same as that in Figure 2. The measurement circuit mainly uses a voltage divider to collect the response voltage at both ends of the tested insulator. The resistance value of resistor 1 is 1.2GΩ, and the resistance value of resistor 2 is 6kΩ.

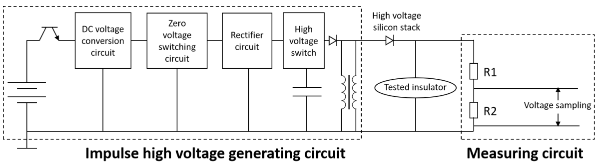

Figure 4 Schematic Diagram of Circuit Design for Detection Method based on Voltage Response Characteristics

When the zero value detection based on voltage response characteristics is carried out with the circuit shown in Figure 4, the voltage-time curves of normal and zero value insulators are shown in Figure 5 and Figure 6.

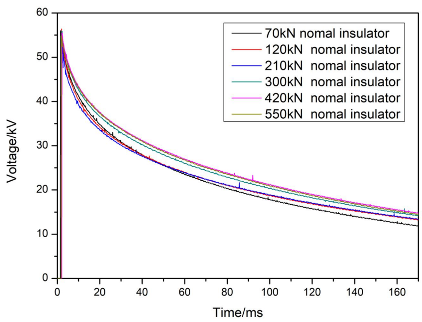

Figure 5 Voltage Time Curve at both Ends of a Normal Insulator based on Voltage Response Characteristic Detection Method

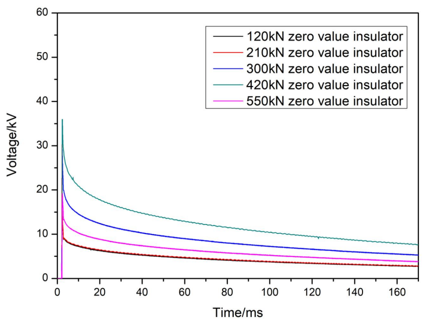

Figure 6 Voltage Time Curve at both Ends of Zero Value Insulator based on Voltage Response Characteristic Detection Method

As shown in Figures 5 and 6, the voltage response-based detection method can accurately distinguish between normal and zero-value insulators. Under 60kV impulse high voltage, normal insulators exhibit peak response voltages exceeding 45kV with slower decay, while zero-value insulators show peak voltages not exceeding 40kV with faster decay. Therefore, the peak response voltage serves as a reliable indicator for differentiating normal and zero-value insulators.

3.2.2 Comparative study of two detection methods in the case of insulator surface contamination

Three standard 210kN insulators were selected. Kaolin and NaCl were prepared to equationte two suspensions: one containing only kaolin and another containing both kaolin and NaCl. Two insulators were coated with kaolin suspension and the mixed suspension, respectively, achieving a surface equivalent ash density of 2.0 mg/cm^2 and an equivalent ash density of 2.0 mg/cm^2 with a salt density of 0.3 mg/cm^2. A third insulator served as a control sample without coating. The three insulators were tested using voltage response and current response characterization methods, with results shown in Figures 7 and 8.

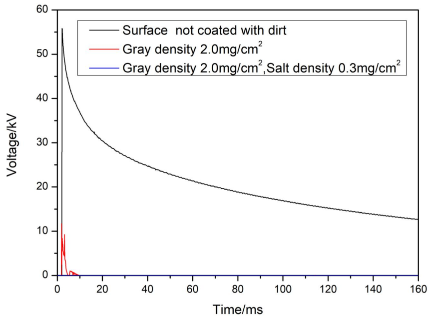

Figure 7 Detection Results Based on Voltage Response Characteristic Detection Method under Surface Contamination of Insulators

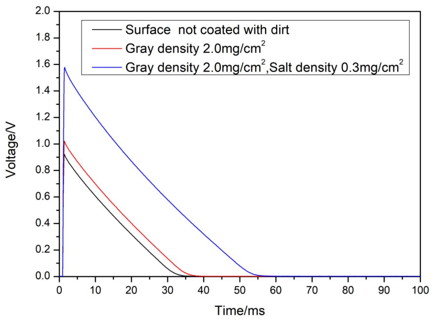

Figure 8 Detection Results Based On Current Response Characteristic Detection Method under Surface Contamination of Insulators

As shown in Figures 7 and 8, when using voltage response-based detection methods, the voltage-time curve exhibits significant changes under normal insulation conditions with 2.0 mg/cm^2 equivalent ash density and no salt density contamination, leading to misclassification as a zero-value insulator. Under similar conditions with 2.0 mg/cm^2 ash density and 0.3 mg/cm^2 salt density, the response voltage drops to zero, resulting in misjudgment. Conversely, current response-based detection methods show no significant changes in the voltage-time curve under normal conditions with 2.0 mg/cm^2 ash density and no salt contamination, preventing misclassification. However, when exposed to severe surface contamination with 2.0 mg/cm^2 ash density and 0.3 mg/cm^2 salt density, the voltage peak exceeds 1.5V, causing false zero-value classification.

Therefore, when the surface of the insulator is contaminated, the detection method based on the voltage response characteristics is more sensitive to the pollution and has a higher risk of misjudgment, while the detection method based on the current response characteristics has a risk of misjudgment only when the surface of the insulator has both ash density and salt density and heavy pollution.

4 CONCLUSION

(1) By analyzing the current response characteristics of porcelain insulators under impulse high voltage, reliable identification of zero-value porcelain insulators can be achieved. The detection circuit incorporates a magnetic ring inductor to convert response current signals into induced voltage signals. Since zero-value and normal insulators exhibit distinct peak values in induced voltage under impulse high voltage, this voltage difference enables accurate differentiation between normal and zero-value insulators.

(2) Under the condition that the surface of the insulator is wet and the surface area is contaminated, the detection method based on the current response characteristics is more reliable than the detection method based on the voltage response characteristics, and the risk of misjudgment is lower.

(3) In the future, it is still necessary to further explore the reason why the detection method based on current response

characteristics is more reliable than the detection method based on voltage response characteristics when the surface resistance of insulators is reduced.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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