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The Application and Improvement of Angle Conversion Technology in the Electrical Test Device for High-Voltage Bushings in Substations

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Abstract

In the development of modern urban construction, in order to ensure the safe and stable operation of high-voltage equipment in substations, by combining electrical test detection and analysis of the insulation performance and internal parameters of high-voltage equipment, systematically understanding the working status of equipment operation, promptly identifying internal defects of equipment and proposing solutions, unnecessary safety risks can be reduced. Therefore, after understanding the current application status of high-voltage bushings and Angle conversion technology in substations, this paper analyzes the design structure of electrical test support for bushings based on the key points and types of existing high-voltage bushings in power transformers, and deeply analyzes the electrical test assembly and disassembly device of high-voltage equipment in substations with Angle conversion as the core and its application effect.

Key words

Angle conversion technology Substation High-voltage bushing Electrical appliance experiment Thread installation and removal.

1. Introduction

As one of the key devices in the power system, the high-voltage bushing of a substation undertakes the insulation and mechanical support functions for high-voltage conductors passing through grounding box shells or walls during operation. Its insulation performance directly affects the safe and stable operation of the entire substation. Therefore, it is of vital importance to conduct regular and accurate electrical tests on high-voltage bushings. Among numerous test projects, the measurement of dielectric loss factor and capacitance is an effective method for diagnosing defects such as insulation aging, moisture absorption, and delamination of bushings, and the Angle conversion technology is precisely the fundamental basis for achieving high-precision measurement. Essentially, the essence of Angle conversion technology is the process of precisely measuring the aforementioned tiny phase difference δ, and using electronic circuits or digital algorithms to convert it into a DC voltage or digital value that is convenient for measurement and processing. In the development of traditional technology, some scholars have applied the balance principle of the Xilin bridge. By adjusting the adjustable resistor and capacitor, the bridge is made balanced. At this time, the dielectric

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loss factor is directly calculated through the geometric relationship of the bridge arm parameters. Modern digital dielectric loss measuring instruments have achieved automated electronic Angle conversion. Their core technologies include signal acquisition, zero-crossing comparison and phase-time conversion, time-voltage conversion and calculation, etc.

Nowadays, domestic research scholars, in the face of large-scale construction battles, have begun to vigorously promote all-digital measurement systems centered on high-performance ADCs, FPgas and DSPS in response to the extreme growth trend in the number of high-voltage equipment. The research focus lies in the rational application of advanced digital algorithms to accurately extract fundamental phase information in a strong noise background. Effectively suppress harmonic interference and white noise. Meanwhile, to address the on-site power frequency interference issue, the device generally adopts a variable frequency measurement mode, which greatly enhances the accuracy and reliability of on-site measurement. It also utilizes artificial intelligence algorithms to integrate and analyze multiple parameters, thereby comprehensively diagnosing and predicting the insulation status of the bushing. The technological development paths studied and applied by foreign scholars are similar to those in China, but they are more distinctive in some cutting-edge technologies and engineering aspects. For instance, equipment not only focuses on application algorithms but also controls data errors through system-level calibration before leaving the factory. Some devices, while ensuring high performance, also guarantee the integration, lightweight and ease of use of the equipment. Some scholars have also proposed to study dielectric loss measurement technology centered on optical current sensors. This technology is regarded as one of the future development directions due to its advantages such as absolute insulation and strong anti-electromagnetic interference ability. However, it is still in the laboratory research stage at present, and the application cost and stability are the main challenges.

Therefore, in response to multiple issues such as the low efficiency and poor safety of the current wiring methods for high-voltage electrical equipment experiments, this paper proposes the application of Angle conversion technology to avoid serious problems caused by inappropriate angles during the wiring process, ensuring the safety of on-site staff as much as possible, and conducting high-voltage equipment experiments and analyses safely and efficiently, thereby obtaining more accurate data results.

2. Methods

2.1. Key Points and Types of High-voltage bushings for Existing power transformers

During the operation of the power system, when choosing the high-voltage bushings for power transformers, both the safety performance of the bushings and the stability of the system operation should be taken into consideration. By mastering the relevant technical principles proficiently, enterprises and users can make more rational choices of casing products that suit their own needs, thereby ensuring the rational utilization of power resources. At present, there are many structural forms of high-voltage bushings, which are classified into different types according to different criteria. The common classification methods and corresponding bushing structural forms are shown in Table 1. On this basis, users can clearly understand the performance and applicable scenarios of various types of

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bushings, thereby providing strong support for the selection of power transformers.

Table 1. Analysis of common casing structure types

No.	Classification Feature	Category
1	Main Insulation Structure	Capacitive
		Non-capacitive
2	Outer Insulation Material	Gas-filled
		Liquid-filled
		Oil-impregnated
		Composite insulation
3	Filling Material Between Core and Outer Insulation	Oil-impregnated
		Oil-filled
		Gas-filled
		SF6-filled
4	Application Medium	Oil-immersed
		Air
		SF6
		SF6-Air
5	Usage Place	Indoor
		Outdoor

2.2. Electrical Test Support Design Structure for casing

The function of the bushing is to enable high-voltage leads to safely pass through walls or power equipment boxes and effectively connect with other equipment. The actual usage scenarios determine its structural requirements and insulation performance. As one of the most effective methods for evaluating the insulation strength of power equipment, the AC withstand voltage test is of great significance for determining whether the power equipment can continue to operate. At present, the national standard "GB 50150-2016 Standard for Handover Tests of Electrical Equipment in Electrical Installation Engineering" stipulates that after handover or major overhaul, the bushings should undergo AC withstand voltage tests, dielectric loss factor tests, and capacitance tests to examine the insulation strength of the main components and solve related technical problems. Some scholars have developed a bushing electrical test support device. The aim is to facilitate the orderly conduct of conduit electrical experiments and enhance the performance and safety of the experiments. The overall experimental setup includes a support body, multiple support rods effectively connected to the support body, and a simulation sheet of the support busbar at the top of the support rods. The overall structural design can ensure complete test conditions at the handover site, guaranteeing sufficient distance from the ground for the test, and achieving higher test efficiency and safety. Meanwhile, the support rods adopted are of a columnar structure with adjustable length The application of the downward concave structure integrated with the top of the support body can simulate the usage site of the casing. Due to the relatively small volume and thin insulation thickness of the casing structure, the test design can propose different dimensions and structural devices for different application sites, thereby meeting the requirements of various casing tests.

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2.3. Electrical test assembly and disassembly device for high-voltage equipment in substations with Angle conversion as the core

Through systematic research on domestic and foreign transformer manufacturers, the design approach centered on Angle adjustment structure was clarified, and the structural design of the high-altitude wiring device was completed by using insulating epoxy resin rods. Among them, the bushings of high-voltage equipment such as lightning arresters and transformers are perpendicular to the ground. However, to ensure air insulation between them, the transformer bushing lifting seat and the transformer main body are generally installed at an Angle, and there is a certain Angle between the lifting seat and the main body. The transformer bushing is vertically installed on the height base, so the transformer bushing is not directly perpendicular to the ground but has a certain inclination Angle. Based on the existing data analysis, for transformers of different voltage levels, the Angle between the transformer bushing and the vertical direction is approximately between 10° and 20°. The actual results are shown in Table 2 below:

Table 2. Analysis results of the angles between the bushings of various grades of transformers and the vertical direction

Voltage Level / kV	Transformer Bushing Angle Range with Vertical Direction / (°)
35	10 ~ 14
110	12 ~ 18
220	10 ~ 20

In this research, the design of electrical testing equipment for high-voltage substations employs angle conversion technology as its core. The adjustable angle range spans from 0 to 30 degrees. To modify the angle of the front-end wire clamp in the wiring device, a movable short rod is utilized in the structural design. As shown in Figure 1, the design primarily utilizes a resin-insulated rod to extend the adjustable angle, combined with a mechanical clamp and an operating handle connected to a sliding clamp. The sliding clamp drives the angle conversion rod, thereby achieving the adjustment of the wire clamp's angle.

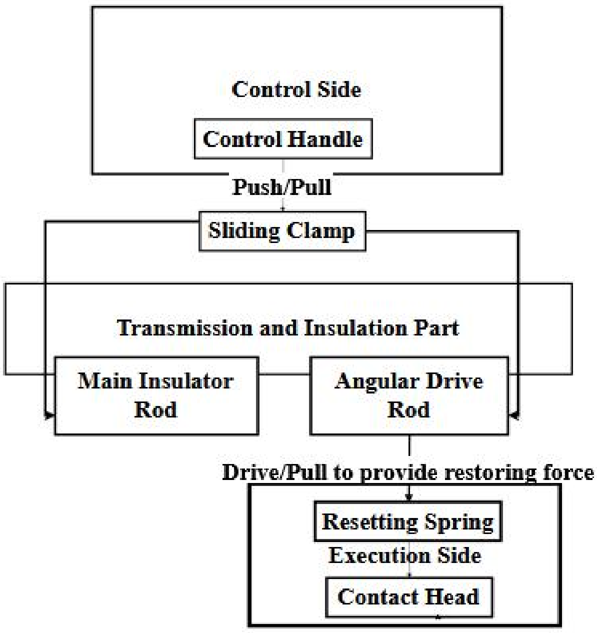

Figure. 1 Angular Adjustment Mechanism Diagram.

When designing the sliding device structure, the angle adjustment mechanism should be integrated with the overall insulating rod through a sliding mechanism. In the manual operation mechanism design, the angle adjustment is achieved by pulling the handle to adjust the mechanism. A limit switch restricts the handle's movement range, preventing incorrect angle adjustments caused by excessive or insufficient pulling. For wiring connection, the upper and lower teeth interlock to complete the wiring process. A fixed pulley installed inside the device guides the telescopic section of the insulating rod to pull the lower tooth's traction line. By adjusting the internal direction through the fixed pulley, the lower tooth moves upward and engages with the upper tooth, enabling high-altitude wiring operations. From a practical application perspective, this integrated design transforms traditional aerial work into ground-based operations, reducing safety risks associated with elevated vehicles and climbing. It enhances operational safety while ensuring precise installation of the wiring device in target areas, resulting in more accurate measurement values.

3. Results

The high-voltage electrical testing of outdoor transformers at a 110kV substation was conducted for analysis. On-site measurements of the 110kV transformer windings' insulation resistance were performed using an insulation resistance tester, with phases A, B, and C selected for testing. Phase A was wired using a high-altitude wiring device for transformer electrical testing, while phases B and C employed conventional manual wiring methods. The comparative test results are detailed in Table 3. During the operation, insulation resistance measurements were sequentially taken between each winding and the ground, as well as between the tested and non-tested windings. To ensure technical safety, all windings and the transformer enclosure were grounded during the insulation resistance measurement process, except for the tested windings.

Table 3. Comparative analysis of experimental test results

Part	Last Insulation Resistance	Current Insulation Resistance
Phase A High Voltage	5189 Ω	5200 Ω
Phase B High Voltage	5288 Ω	5325 Ω
Phase C High Voltage	5215 Ω	5355 Ω

Combined with Table 3, the actual result of insulation resistance measurement of A-phase wiring using high-altitude wiring device for transformer electrical test is closer to the latest measurement result. This result proves that high-altitude wiring device for transformer electrical test can safely and firmly complete electrical test wiring.

4. Conclusion

This study demonstrates that the angle conversion technology applied in designing the experimental wire assembly/disassembly device fulfills the technical requirements for rapid and safe wiring in field electrical testing. It enhances operational efficiency for equipment field testing, provides fundamental evidence for ensuring the safe and stable operation of power systems, and the collected data offers new directions for addressing practical challenges.

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