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Adjustable Method and Implementing Device for Direct Current Ice-Melting Discharge Clearances

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Abstract: In response to the significant threat of ice damage faced by power transmission lines during ice-melting periods, traditional adjustments of discharge clearances in the direct current ice-melting process often rely on manual tower climbing operations. This approach not only suffers from low efficiency and high safety risks but also struggles to meet the rapid response requirements under complex meteorological conditions. To address these challenges, this paper introduces a method and complementary implementing device for adjusting discharge clearances in direct current ice-melting processes. The device achieves this by reliably serially connecting the downlead conductors on both sides of the pole through specialized downlead conductor clamps and integrating a remotely controllable automatic knife switch, constructing an electrically isolated discharge clearance adjustment mechanism. During lightning protection period, the remote control device at the base of the tower closes the electric knife switch to establish an electrical pathway. As the ice-melting period commences, the same remote control system remotely opens the knife switch, facilitating flexible adjustment of ice-melting clearances. This method effectively replaces the traditional manual tower climbing short-circuit method, significantly improving operational convenience and response speed. Real-world operational results demonstrate that this device can swiftly, efficiently, and safely complete the task of adjusting discharge clearances, markedly enhancing the overall efficiency of direct current ice-melting operations. Furthermore, it enhances dielectric reliability, ensures the safety of operators, and offers new technical support for ice disaster prevention in power transmission lines.

Keywords: Discharge Clearances; Electric Knife Switch; Remote Control Device; Power Transmission Line Safety

1. Introduction

Currently, Optical Ground Wire (OPGW) systems primarily employ tower-by-tower grounding methods, while conventional ground wires often utilize segmented insulation and single-point grounding. Due to electrostatic coupling and electromagnetic induction between ground wires and alternating current transmission conductors, induced voltages, static induction currents, and electromagnetic induction currents can occur on the ground wires, leading to circulating losses in OPGW and adversely affecting the energy-saving efficiency of power transmission lines. Additionally, differences in grounding methods for conventional ground wires and OPGW on the same tower can increase the likelihood of lightning strikes on OPGW, resulting in issues such as strand breakage [1-4].

Discharge clearances, also known as protective clearances, play a role in lightning protection during normal operation of power transmission lines and serve as the ice-melting medium during ice season. During thunderstorm periods as per design requirements, the corresponding tower positions' discharge clearances need to be manually short-circuited, which should be restored to their original state during the ice season. It is essential to select appropriate insulation configurations based on different voltage levels, with the air clearances for ice-melting overhead ground wires typically ranging from 20 to 150mm. The clearance distances must be installed strictly according to design specifications, with a permissible deviation of ±2mm [5]. During the manual short-circuiting process, failure to meet the design requirements for short-circuit quality and adjustment of discharge clearance distances can result in the melting of discharge clearances, leading to unsuccessful ice-melting and suboptimal lightning protection grounding, along with challenges such as delayed tower climbing due to weather conditions. It is evident that the quality of short-circuiting discharge clearances and the adjustment of clearance distances are crucial factors influencing the stable operation of power transmission lines and the effectiveness of ice melting procedures. Therefore, there is an urgent need to research an automatic short-circuit discharge clearance technology and its corresponding device.

2. Determination of Automatic Short-Circuit Discharge Clearance Technology and Device Scheme

As illustrated in Figure 1, the comprehensive operation and maintenance of the typical 500 kV insulated ground wire line are under the responsibility of Zhaotong Power Supply Bureau. Zhaotong is located in the northeastern part of Yunnan Province, where snow and ice disasters are prevalent, leading to severe icing conditions along the transmission lines [6]. To address this, Yunnan Power Grid Corporation adopts direct current ice-melting technology, primarily focusing on ice-melting overhead ground wires. This process necessitates insulating all ground wires at each base tower and installing ground wire insulators and discharge clearance gaps at the connection points between the ground wires and the towers, thereby undertaking ground wire insulation transformation projects [7].

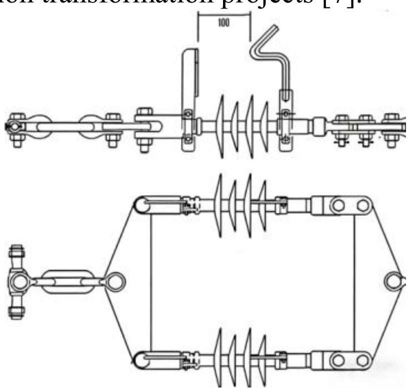

Figure 1. Schematic Diagram of Grounding Line Fittings

2.1 Non-Disassemblable Innovative Discharge Clearance

Without altering the original alignment of the ground wires and maintaining the existing insulators and discharge clearances within the lines, only the upper portion of the discharge clearance, as depicted in Figure 1, is modified: a non-disassemblable innovative discharge clearance. This device can be folded during the ice season and extended during lightning protection periods, providing both ice-melting and lightning protection functions. Additionally, it is resistant to wind pressure, ensuring stability and preventing loosening or detachment. This design is compatible with various types of rod insulator locking new types of discharge clearances.

2.2 Installation of Electric Knife Switch for Discharge Clearance Transformation

By removing the original discharge clearance, the ground wire is guided to the first platform of the iron tower using downlead conductors and clamps, where it is connected to an electric knife switch. The electric knife switch replaces the discharge clearance to facilitate grounding and insulation of the ground wire. Following a technical scheme comparison, the chosen development approach is the installation of electric knife switches for transforming discharge clearances.

3. Development Process of Automatic Short-Circuit Discharge Clearance Technology and Device

3.1 General Principles and Implementation Methods

The development of automatic short-circuit discharge clearance technology and its device consists primarily of two aspects: overhead ground wire transformation and discharge clearance modification, as depicted in Figure 2.

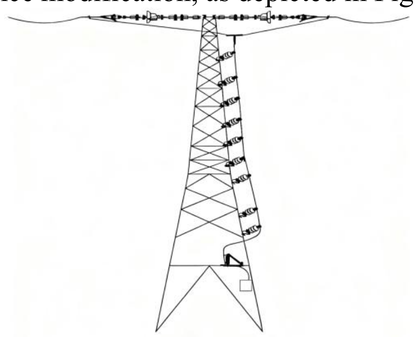

Figure 2. Schematic Diagram of Automatic Short-Circuit Discharge Gap Device

(1) Overhead Ground Wire Transformation: A set of TY-type clamps is installed in the middle of the ground wire downlead conductors on both sides of the tower. An additional downlead conductor is taken below, leading to the first

platform. Insulated lead-down clamps are installed between the tower and the downlead conductor to establish a connection through insulated lead-down clamps, establishing galvanic isolation between the tower and the downlead conductor.

(2) Discharge Clearance Modification: The downlead conductor is connected to an electric knife switch at the first platform, enabling the overhead ground wire to be grounded upon opening the breaker, thereby fulfilling the role of the discharge clearance. During normal operations requiring lightning protection, the electric knife switch is in the closed position, grounding the overhead ground wire. In ice-melting conditions, the electric knife switch is opened in advance, placing it in the open position.

3.2 Specific Implementation Methods

The specific implementation methods are detailed in Figure 3:

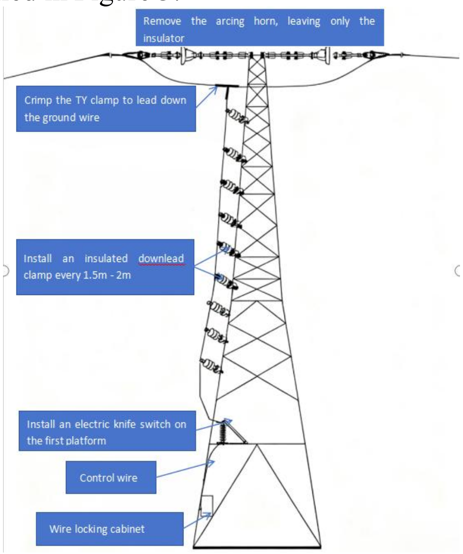

Figure 3. Schematic Diagram of Implementation Method for Automatic Short-Circuit Discharge Gap Device

(1) Preserve the insulators of the overhead ground wire while removing the original discharge clearance on the insulators. At this stage, the overhead line remains ungrounded, rendering it ineffective for lightning protection.

(2) Install a set of TY-type clamps on the downlead conductor of the overhead ground wire, with the lower end of the TY-type clamp connected to a downlead conductor running along the tower legs. Install a set of insulated lead-down clamps at intervals of 1.5m to 2m on the downlead conductor, ensuring that the downlead conductor maintains a safe electrical distance from the tower body. Extend the downlead conductor downward to the first platform of the tower, where we compress a downlead conductor clamp to the lower end of the downlead conductor, which is then connected to an electric knife switch terminal board. [8]

(3) Secure the electric knife switch to the tower material using U-shaped fixtures, connect the control line of the electric knife switch, and gather any excess control lines into the locking cabinet (located 2m away on the ground).

3.3 Specific Operating Procedures

As depicted in Figure 4, when ice-melting is required, personnel at the base of the tower connect the operating line to the control box. The control box is linked to the battery via a power line. Upon switching on, operators should press the "trip 2" button, causing the motor to rotate clockwise. This rotation drives both the driving gear and driven gear, inducing a clockwise rotational motion in the shaft. The shaft is equipped with cam-actuated protrusions; when these protrusions reach a certain angle, they make contact with a contact switch. Once the indicator light on the control box turns green, signaling that the discharge clearance has reached the ice-melting state, the dispatcher is informed and can proceed with grounding wire ice-melting operations. After the ice-melting process is completed, upon receiving notification from the dispatcher to close the circuit, operators press the "close" button. The motor continues its clockwise rotation, and after the shaft turns 180°, it triggers the motor to power off again by making contact with the contact switch, placing the discharge clearance in a lightning protection state. During normal lightning protection operations, based on the voltage level, pressing the "trip 1" button initiates the motor's clockwise rotation. Once the shaft rotates 90° and contacts the contact switch, the motor is deactivated, placing the discharge clearance in a lightning protection short-clearance state. [9-10]

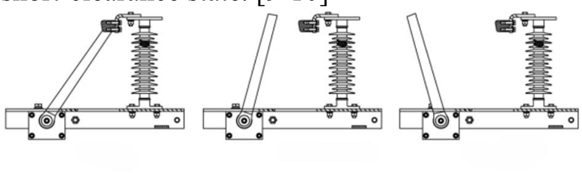

Figure 4. Schematic Diagram of Electrically Operated Grounding Knife Switch

After this device was put into operation at multiple power line sites, it achieved significant effects:

(1) Efficient and Convenient:

Through remote operation of the electric knife switch at the tower base, the adjustment time of the discharge clearance was reduced from several hours of traditional manual tower climbing to a few minutes, greatly enhancing response speed, especially noticeable in adverse weather conditions or urgent ice melting requirements.

(2) Safe and Reliable:

1. Completely eliminates the high-altitude operation risks of short-circuiting or adjusting clearances by manually climbing towers, ensuring personnel safety.

2. The electric knife switch maintains stable and reliable contact force in the closed state (ensured by the supporting pin structure), and in the open state, the insulation distance is precisely controllable (maintaining clearance tolerance within ±2 mm), effectively addressing issues like melting gaps caused by poor manual short-circuit quality or inaccurate gap adjustments, poor lightning protection grounding, or failed ice melting.

3. The downlead conductor is fixed with insulated downlead conductor clamps to maintain a safe distance from the tower body, ensuring overall structural stability (secured by U-shaped fixtures and aviation plug connections) and strong wind pressure resistance.

(3) Comprehensive Functionality:

1. During lightning protection periods, the reliable closure of the electric knife switch ensures proper grounding of overhead ground wires, meeting lightning protection requirements.

2. During icing periods, the precise opening of the electric knife switch creates a discharge clearance within design specifications (20-150mm), serving as a crucial medium for the smooth flow of ice melting currents in the direct current ice melting circuit.

(4) Versatility:

The device retrofit scheme (retaining original insulators, adding downlead conductors and electric knife switches) requires minimal modifications to existing lines, making it easy to promote and install on existing lines. The remote control operation is straightforward and intuitive (controlled by button operation on the control box, with clear indicator light statuses), making it easy for maintenance personnel to master.

(5) Application Scenario:

This device has been successfully applied in multiple ice-prone lines of different voltage levels (such as 110kV, 220kV). Enduring practical tests during various lightning protection seasons and winter icing periods, the device operates stably, with a high success rate for remote operations and excellent ice melting effects. There have been no incidents of ice melting failures or lightning protection inadequacies due to clearance issues, significantly enhancing the operational reliability of the lines in complex weather conditions.

4. Conclusions

This paper addresses the prominent issues of low efficiency, high safety risks, and difficulty in ensuring accuracy associated with the traditional manual short-circuiting during lightning protection periods and manual restoration during icing periods for discharge clearances on power transmission lines. To tackle these challenges, a method for adjustable direct current ice melting discharge clearance based on electric knife switches and its implementing device has been successfully developed. The core features of this device include:

Innovative Structure: By transforming the overhead ground wire downlead conductor into an insulated form (by adding TY-type clamps, downlead conductors, and insulated downlead conductor clamps) and installing a custom-made electric knife switch on the first platform of the iron tower, the controllable conversion of the ground wire's grounding/insulation status has been achieved.

Intelligent Control: Operating the electric knife switch through remote control at the tower base, its precise gear transmission mechanism, contact switches, and cam design ensure accurate and reliable switch positions (meeting the ±2mm clearance requirement), with an intuitive indicator light system providing feedback on operational status.

Safety and Efficiency: By completely eliminating the risks associated with manual tower climbing operations, the adjustment time for clearances has been reduced from hours to minutes, significantly enhancing operational efficiency and safety.

Practical applications have demonstrated that this device operates stably and reliably, with straightforward operation, enabling quick, precise, and safe automatic switching between discharge clearances in lightning protection grounding status and ice melting insulation status. It effectively resolves many drawbacks associated with manual adjustments. Its successful implementation has not only significantly improved the efficiency and success rate of ice melting on power lines but also greatly enhances the reliability of lightning protection and ensures the personal safety of maintenance personnel. This technology provides robust technical support for enhancing the safety and stability of power grids under adverse weather conditions. Its practical value and broad prospects for application make it a promising advancement in the field.

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