110kV Lightning-proof and Ice-proof Insulators and Explosion-proof Research

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Abstract: At present, the transmission line realizes the effect of lightning protection and supporting wires by connecting insulators and lightning arresters in parallel. However, due to the large weight and volume of lightning arresters, the space of the cross arm of the iron tower is limited, the workload of lightning arresters installation and line operation and maintenance is greatly increased, and the live operation is more difficult. Aiming at the problems that lightning arresters do not have the ability to hang wires, and additional hanging points are needed during installation, and the cross arm of iron tower is reformed, this paper proposes a lightning protection composite insulator combining lightning arresters and insulators. In view of the anti-explosion performance of lightning arresters, the existing research mostly focuses on the discussion and theoretical analysis of lightning arresters explosion accidents, and seldom involves the anti-explosion performance test of lightning arresters. In this paper, the practicability and reliability of the 110kV lightning-proof and ice-proof insulator are illustrated through the explosion-proof performance test and mechanical performance test of the proposed 110kV lightning-proof and ice-proof insulator.

1. Introduction
The 110kV AC overhead transmission line has a long transmission distance and a wide crossing area. It often crosses some mountainous areas with complex topography and is subject to severe weather tests such as lightning strike, rainstorm and icing. When the sealing performance of the lightning arrester is poor or the resistance piece is seriously deteriorated, the lightning arrester is easy to be damaged or even exploded. Therefore, the explosion-proof performance of lightning arresters is particularly important for the stable operation of transmission lines to avoid the phenomenon of "string dropping". Surge arresters must ensure that there is a pressure relief device inside them to avoid the explosion of surge arresters, and at the same time must ensure the stability of oxide resistors to protect electrical equipment [1-2].

The main causes of explosion in the operation of lightning arrester are: poor sealing performance of zinc oxide lightning arrester, moisture immersion, damage to internal insulation, acceleration of deterioration of resistor sheet and explosion; With the increase of MOA operation years, the resistance piece has poor anti-aging performance, resulting in an increase of leakage current, and long-term operation leads to thermal collapse of MOA and explosion of lightning arrester body. The resistance piece is weak in withstanding square wave impact. When the lightning current amplitude is too large, lightning strike damage to lightning arrester will be caused [3-6].

Literature [7-14] mainly analyzes the causes of defects and failures through lightning arrester damage or explosion cases. It is considered that the main causes of lightning arrester damage or explosion are the overall sealing performance of lightning arrester body, the selection of anti-explosion film material and the design of anti-explosion structure, and whether there are bubbles, impurities or moisture inside...
the epoxy glass fiber wound resistor column or silicone rubber umbrella skirt jacket when pouring. This paper proposes a 110kV lightning-proof and ice-proof insulator which combines lightning arrester and insulator, realizes the lightning protection effect of supporting conductor and line, and solves the problems of heavy workload of lightning arrester installation, line operation and maintenance, and great difficulty in live operation. According to the proposed 110kV lightning-proof and ice-proof insulator, anti-explosion design and performance test are carried out, which shows the practicability of 110kV lightning-proof and ice-proof insulator.

2. 110kV Anti-icing and Lightning Protection Composite Insulator Structure

The external insulation structure and physical diagram of 110kV lightning-proof and ice-proof insulator are shown in fig. 1. The 110kV lightning-proof and ice-proof insulator consists of an insulation section and a lightning protection section. The umbrella skirt of the insulation section is made of silicone rubber material, and the umbrella skirt structure of the insulation section adopts a flower arrangement structure, which increases the bridging time of the umbrella skirt covered with ice and improves the insulation strength of the insulator. The main technical parameters of the 110kV lightning-proof and ice-proof insulator are shown in Table 1.

![Fig.1 The outer insulation structure diagram of 110kV lightning-proof and ice-proof insulator](image)

Under the normal operation of the line, the insulation section bears the voltage, and the lightning protection section has very little current, thus solving the aging problem of the resistor. When the line is struck by lightning, the equalizing ring in the insulation section breaks down, and the resistance piece changes from a high resistance state to a low resistance state, completing discharge and releasing energy, and the insulation recovers when the voltage drops.

![Tab.1 Main technical parameters of 110kV lightning-proof and ice-proof insulator](image)

| Construction length | 1314±5mm | Rated voltage | 110kV |
|---------------------|----------|---------------|-------|
| Climbing distance of lightning protection section and insulation section | 2170mm/2170mm | Reference voltage of arrester at DC 1mA | >130 kV |
| Diameter of epoxy mandrel | ø24 | Lightning impulse current residual voltage | ≤ 260kV |
| Rated mechanical load | 120kN | Lightning Strike 50% Discharge Voltage | ≥ 525 kV |
| 2ms square wave withstand current | 800A | Power-frequency withstand voltage | ± 370 kV |

3. Explosion-proof structural design

After the explosion-proof structure of the traditional lightning arrester is destroyed, the structural strength of the lightning arrester decreases significantly. The current explosion-proof structure cannot meet the operation requirements of lightning-proof and ice-proof composite insulators.

In this paper, multi-layer sealing measures and high temperature silicone rubber filling technology with flame retardant performance are adopted to improve the sealing performance. The explosion-proof structure design is shown in the following figure. The multi-core rod structure effectively expands the pressure weak area, the pressure spreads evenly, and the internal mechanical structure is effectively protected. The insulating cylinder is of a hollow insulating cylinder structure, the end of which can be sealed, the middle of which is composed of dozens of glass fiber reinforced polymer rods with a diameter of about 5mm into a cylindrical arrangement, and the outside of the zinc oxide resistor sheet is wound
with glass fiber cloth. Even if there is an electric arc, the electric arc can be led out to the outer air gap through the weak point of mechanical strength, and a stable electric arc cannot be formed inside.

Three relatively independent sealed spaces are arranged in the insulating cylinder. The cylinders at both ends adopt compression spring spaces to provide contact pressure of the resistor pieces. The glass fiber core rod cylinder is adopted in the middle part, and the gap of the core rod is a pressure weak point, which can effectively release the pressure caused by internal arc fault and prevent large fragments from splashing outward.

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**4. Test apparatus**

The explosion-proof test of 110kV lightning-proof and ice-proof insulator is carried out by using a large-capacity power frequency current generator. Through laying short-circuit fuse and applying processing frequency short-circuit current, short-circuit tests of large current (effective value 20kA, duration 0.2s) and small current (effective value 800A, duration 1s) are respectively carried out to simulate short-circuit faults so as to test the explosion-proof performance of lightning-proof and ice-proof insulators.

According to the standards of GBT 32520-2016 "Metal Oxide Arrester with Out-of-Band Series Gap for Overhead Transmission and Distribution Lines Above 1kV AC" and the requirements of Document [15], 800A Small Current Short Circuit Test and 20kA Large Current Short Circuit Test are carried out on 110kV lightning-proof and ice-proof insulator. The test shall show that the failure of the test product will not cause the shattering blasting of the test product jacket, and the test product itself and any ejected components must automatically extinguish the open flame within 2min.

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**5. Analysis of Test results**

**5.1 800A Low Current Short Circuit Test**

The arc development process of the test sample photographed by a high-speed camera is shown in fig. 4. When the voltage is applied to the embedded fuse, the power frequency short-circuit current is instantaneously generated, resulting in hot arc and arc light. Since the power frequency short-circuit arc is sine wave and lasts for 50 cycles, the repeated process of "arcing, arc strengthening and arc brightening, arc weakening, arc darkening and arc re-strengthening" occurs during the test.

During the test, no comminuted explosion occurred on the 110kV lightning-proof and ice-proof insulator. The power frequency current arc continued to burn along the embedded short-circuit fuse. The generated pressure was released along the explosion-proof slot, tearing the umbrella group at the position of the explosion-proof slot. No explosion and open flame combustion occurred, thus meeting the explosion-proof performance requirements.

The sample condition after the small current short circuit test is shown in fig. 5. During the
continuous combustion of the power frequency current arc, the fuse will generate strong energy and temperature rise, and generate huge pressure in the local space. When the pressure exceeds the compression value of the set explosion-proof tank (pressure release weak point), the explosion-proof tank will be broken through, the arc will be ejected from the explosion-proof tank at high speed and accompanied by blazing white light, tearing and burning a composite umbrella skirt near the explosion-proof tank, so the damage degree of the umbrella skirt near the explosion-proof tank is more serious than other positions. Since the power frequency short-circuit arc releases energy and pressure from the explosion-proof groove, which is equivalent to protecting the umbrella skirt and internal ZnO resistor pieces at other positions, the epoxy cylinder at the non-explosion-proof groove position inside the lightning-proof and ice-proof insulator remains intact after the 800A low-current short-circuit test.

![Figure 4: Development of arc in 800A and 1s low current short circuit test (left)](image)

![Figure 5: Sample conditions after small current short circuit test (right)](image)

5.2 20kA High Current Short Circuit Test

In the process of 20kA power frequency current and 0.2s duration high current short circuit test, the high-speed camera is also used to photograph the arcing, arc duration and extinguishing process of the sample, as shown in fig. 6. The arcing process is similar to the 800A low-current short circuit test. During the test, there are repeated processes of "arching, arc strengthening and brightening, arc weakening, arc darkening and arc re-strengthening".

During the test, the 110kV lightning-proof and ice-proof insulator did not suffer from comminated explosion. The power frequency current arc continued to burn along the embedded short-circuit fuse. The generated pressure was released along the explosion-proof slot, tearing the three umbrella groups at the location of the explosion-proof slot. No explosion and open flame combustion occurred, thus meeting the explosion-proof performance requirements.

The situation of the sample after the high current short circuit test is shown in fig. 7. As the applied power frequency current is larger, the energy and temperature generated on the fuse are also higher. The released huge pressure will break through the explosion-proof tank and then tear the three nearby umbrella skirts. At the same time, there is a 15cm longitudinal split on the lightning protection section composite jacket, and the ablation of other nearby umbrella skirts is more serious. At the same time, the temperature rise caused by power frequency short-circuit current also burns and melts the surface of insulator ball socket fittings. The power frequency short-circuit arc releases energy and pressure from the explosion-proof tank location. However, due to the large short-circuit current, the epoxy cylinder at the explosion-proof tank location has a 15cm long crack, the entire surface of the epoxy cylinder is blackened, and the insulation glaze on the surface of the zinc oxide resistor sheet and the internal ZnO
blackening phenomenon are serious, but the core rod is not damaged, thus avoiding the risk of string dropping.

![Image of arc combustion process in 20kA, 0.2s high current short circuit test](a) (b) (c)

![Image of sample conditions after high current short circuit test](a) (b) (c)

Fig.6 Arc combustion process in 20kA, 0.2s high current short circuit test

Fig.7 Sample conditions after high current short circuit test

5.3 Mechanical characteristics

According to the standard of DLT 815-2002 Composite Coat Metal Oxide Arrester for AC Transmission Line, the mechanical performance test of 110kV lightning-proof and ice-proof insulator is carried out, and the arrangement is shown in Figure 8. Tensile force was applied in stages during the experiment. After withstanding 120kN tensile force for 1min, the appearance of insulator did not change abnormally. Moreover, the mechanical tensile failure load is 155.7kN, which meets the requirements of design and grid operation (exceeding the current design requirement of 110kV composite insulator tensile strength of 70kN).

![Image of test layout of mechanical performance of 110kV lightning-proof and ice-proof insulators](a) Layout of Tensile Test before Explosion-proof Test

(b) Layout of Tensile Test before Explosion-proof Test

Fig.8 Test layout of mechanical performance of 110kV lightning-proof and ice-proof insulators

The 800A low-current short-circuit test sample is first applied with a pulling force of 100kN and 1min, and then applied with a pulling force of 120kN and 1 min. Tensions of 80kN(1min), 100kN(1min) and 120kN(1min) were applied to 20kA high current short circuit test samples respectively.

The tensile test results of 110kV lightning-proof and ice-proof insulators before and after 800A small current short circuit test and 20kA large current short circuit test are shown in Table 2.
Tab.2 Tensile test results of 110kV lightning-proof and ice-proof insulators

| Test items                        | Tolerant load | Damage load |
|-----------------------------------|---------------|-------------|
| Explosion-proof test              | 120kN/1min    | 155.7kN     |
| After 800A small current short circuit test | 120kN/1min | /           |
| After 20kA high current short circuit test | 120kN/1min | /           |

From the above results, it can be seen that the 110kV lightning-proof and ice-proof insulator after 800A small current short circuit test and 20kA large current short circuit test both passed the 120kN rated mechanical load test, and the appearance of the insulator did not change abnormally after the test. The structural design problem of lightning arrester with explosion-proof and tensile properties is solved, and the function fusion of insulator lightning arrester is realized.

The above test results show that even if the 110kV anti-lightning and anti-icing insulator has a body fault (the resistor is damaged) after being hung up, the destructive explosion and insulator string falling phenomenon caused by power frequency short-circuit current will not occur when being struck by lightning, thus meeting the operation requirements of hanging up the network.

6. Conclusion

1. The 110kV lightning-proof and ice-proof insulator is composed of an insulation section and a lightning protection section, and has the functions of an insulator and a lightning arrester. The umbrella skirt structure of the insulation section adopts a flower arrangement structure, and has the functions of lightning protection and anti-icing of lines and wire support.

2. The 110kV lightning-proof and ice-proof insulator passes the 800A low-current short-circuit test and the 20kA high-current short-circuit test, which will not lead to the shattering explosion of the test article jacket, and will automatically extinguish the invented open flame (if any) within the specified time. After the test, the mechanical performance still meets the requirements of the line and the explosion-proof performance is good.

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