Research on Anti-Icing Technology of High Voltage Line Insulator Based on Advanced Sensor

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Abstract. The insulator has an ice flashover failure. To reduce the calculation error of the equivalent icing thickness of transmission lines due to the insufficient number of sensors, a new online monitoring device for wire icing based on 3 sets of force sensors and inclination sensors was designed. The device integrates multiple monitoring functions such as micro-meteorology, wire temperature, distributed multi-rod tension, and images. The study found that the main reason for the ice flash of insulators is that the ice bridging the insulation on the string skirt. The high conductivity of melting ice water causes the ice flash voltage to be too low. A water curtain that blocks the melted ice water with high conductivity from forming a flashover channel. It is a basic measure to improve the ice-coated insulation and the flashover voltage of the ice string.

Keywords: Transmission line, ice and snow disaster, insulator, icing, flashover.

1. Introduction
China is one of the countries with the most severe icing on transmission lines in the world. Since there were records of ice disasters on transmission lines in 1954, large-scale ice disasters occurred across the country from 1974 to 1976, 1984, 2005, and 2008. From January to February 2008, Central China, East China, Southwest China, etc. Heavy snowstorms and freezing rain in the region once in 50 years caused large areas of ice on transmission lines and towers of power grids in Henan, Hunan, Hubei, Jiangxi, Sichuan, Chongqing, Zhejiang, Anhui, Guangxi, Guizhou and Yunnan, and transmission and transformation facilities. The damage was severe, which had a serious impact on the national economy and people's lives.

At present, many research results of icing on transmission lines at home and abroad mainly focus on the causes, mechanisms, conditions, influencing factors, icing process and flashover of insulators, etc., and on-line icing monitoring and early warning technology, some devices have also been developed and run on-line. However, due to the insufficient number of sensors, these ice-coating monitoring devices have made many simplifications in the process of establishing the ice-coating thickness model. They have not considered the influence of the ice coating on the central poles on the wires on both sides of the poles, and ignored the influence of parameters such as wire temperature on the wires [1]. The influence of icing causes large errors in the calculation of icing thickness during
actual operation, and it is impossible to obtain important information such as the icing density and type of the wire.

In view of these situations, the new online monitoring device for wire icing on transmission lines studied in this paper increases the number of sensors, can obtain the wire icing conditions of 3 base poles at the same time, and realizes real-time monitoring of wire temperature, which can be considered in the model establishment process. Based on the influence of wire temperature on the calculation results, the calculation model of equivalent icing thickness established based on this is more in line with the actual icing situation [2]. At the same time, the sensor monitoring technology is combined with the image monitoring technology, and finally the important information required for dicing and melting of the iced line, such as the thickness, density and type of the ice coating on the wire, is given.

2. Common types and effects of icing

The common types of icing in mountainous areas in China are rime, rime, and mixed rime. The special geographical environment of China's mountainous areas often causes the central and top mountainous areas to form an inversion layer in winter due to the influence of the north-south cold and warm air flow. Therefore, it is prone to catastrophic weather of freezing rain, which in turn causes rime and ice on the line. The rime in this area is generally formed by freezing rain. The surface is relatively smooth and hard. It is transparent or white and transparent due to the inclusion of a large number of air bubbles. It has strong adhesion and its specific gravity is the largest among several icing forms, generally 0.80–0.92 g/cm³; rime is formed by freezing of supercooled clouds or very small water particles when the temperature is low (-3--25) °C, there is dense fog, and the wind speed is 0-5 m/s. Rime is characterized by fine organization, fluffy structure, small adhesion, white colour, and easy to fall off when subjected to external force vibration or melting. The specific gravity of rime is generally small, ranging from 0.1 to 0.4 g/cm³. When the rime is severely icing, the upper and lower surfaces of the umbrella skirts of the insulator string are wrapped by rime in the wind, and the rims between the sheds are filled with rime, and even a cylindrical ice-coated whole is formed. Mixed rime is a form of mixed icing that is between rime and rime but is similar to rime [3]. The mixed rime structure is dense layered, transparent and opaque appear alternately, and the specific gravity is 0.6-0.8 g/cm³. Among the three types of icing, rime is the most harmful type of icing to the transmission line. It can not only cause flashover of the insulator string, but also cause the line inverted pole disconnection accident caused by the icing of the conductor and the ground wire. The icing form in the mountainous areas of central China in Shaanxi is mainly mixed rime icing.

3. Ice flash mechanism and influencing factors

3.1. Ice flash mechanism

Ice coating is a special kind of pollution. During the ice melting process, a conductive water film will form on the surface of the insulator. Therefore, ice flash is similar to pollution flash discharge. The discharge process is also caused by surface leakage current, but its discharge mechanism is different from that of pollution flash. The icing not only causes the distortion of the voltage distribution of the insulator string, but also causes the distortion of the surface voltage distribution of the monolithic insulator [4]. This voltage distribution distortion is one of the main reasons for the drop of the ice flashover voltage of the insulator string. The voltage distribution of XP-70 insulator 7-slice string is shown in Figure 1.
Figure 1. Voltage distribution of XP-70 insulator 7-slice string

The flashover process of ice-coated insulators is as follows: icing causes distortion in the voltage distribution of the insulator (string), and the grounding terminal, especially the high-voltage terminal, bears a large voltage; as the voltage increases, the high-voltage terminal and the grounding terminal of the insulator string become blue-violet the current is generally in the range of 5-20mA. At this time, the ice begins to melt obviously; the voltage continues to rise [5]. When the current exceeds 20mA, the blue-violet spark turns into pink and suddenly becomes a white arc. When the current reaches 250mA, the intermittent white arc burns and develops steadily, and each segment of the arc quickly connects and crosses about 70% of the string length; when the arc current exceeds 450mA, the arc quickly connects to the two poles to complete the flashover.

3.2. Factors affecting ice flashover of ice-coated insulators

There are many factors that affect the icing of line insulators. There are many relevant literatures at home and abroad. In summary, they mainly include meteorological conditions, topography and geographic conditions, altitude, and seasonal influences. The test results show that icing causes distortion of the voltage distribution of the insulator string. The uneven icing on the upper and lower surfaces can also cause distortion of the surface voltage distribution of the monolithic insulator. The heavier the icing, the more serious the voltage distribution distortion; the two ends of the insulator string, especially the high voltage lead end insulators withstand the highest percentage of voltage, which causes these parts to discharge and arc first, and when the arc develops to a certain extent, it gradually extends upwards [6]. At this time, due to the ice layer Melting, the leakage current is also large, further aggravating the development of the arc, and finally the insulator string flashover along the surface.

3.3. Factors affecting calculation formula analysis

3.3.1. The impact of pollution. Clean ice (the ice layer does not contain other impurities) or the ice layer with low conductivity of ice-coated water will not significantly reduce the ice flashover voltage of the insulator, only the presence of dirt in the ice layer, that is, the insulator has been the flashover voltage will be significantly reduced when the ice-coated water is contaminated or contaminated during the icing process. As the degree of contamination (ice-coated water conductivity or salt density) increases, the flashover voltage of the ice-coated insulator will decrease significantly. The influence of pollution on the flashover voltage of ice-coated insulators can also be expressed as

$$U_f = MS^{-b}$$

(1)
In the formula: $U_f$ is the flashover voltage, kV; $M$ is the coefficient determined by the insulator type, string length, altitude, etc.; $S$ is the pollution degree, which can be characterized by the conductivity of iced water $\gamma = 20$ or salt density, respectively; $b$ is the pollution degree Characteristic index of the influence on ice voltage.

3.3.2. The influence of the amount of icing. Regardless of the thickness or quality of ice coating, the effect of ice coating on the flashover voltage of insulators is aggravated as the amount of ice coating increases, but when the amount of ice coating reaches a certain level, the minimum flashover voltage decreases. It's not obvious anymore. The influence of the amount of ice coating on the ice flash voltage can be expressed as

$$U_f(W) = U_f(0)e^{-mW}$$

(2)

In the formula: $U_f(W), U_f(0)$ is the flashover voltage at $W$ (in kg) and 0, respectively, for the amount of icing, kV; $m$ is a characteristic index that characterizes the influence of the amount of icing. Some scholars pointed out that the influence of icing thickness on the ice flashover voltage of insulators is affected by pollution. When there is pollution, the influence is weakened.

3.3.3. The influence of altitude. Since icing is a conductive substance, the ice flash voltage of insulators gradually decreases with the increase in altitude and the decrease of air pressure. The influence of air pressure on ice flash voltage can be expressed as

$$U_f = U_{f,0}\left(\frac{P}{P_0}\right)^{n}$$

(3)

In the formula: $U_f, U_{f,0}$ is the flashover voltage under atmospheric pressure $P$ and standard atmospheric pressure $P_0$ respectively, in kV; $n$ is the characteristic index of the influence of atmospheric pressure. $n$ is different when the insulator type, voltage polarity, degree of icing, and degree of contamination are different.

4. Monitoring system design

The new-type wire ice on-line monitoring device designed in the thesis is mainly composed of the main extension of the tower monitoring, the auxiliary extension of the large side and the trumpet side, and the wireless communication network. The overall structure of the device is shown in Figure 2.

![Figure 2. Overall structure of the device](image)
The device integrates multiple functions such as micro-weather monitoring, wire temperature monitoring, distributed multi-pole tower tension monitoring, and image monitoring. The whole device adopts the structure design of main extension + double auxiliary extension. Among them, the monitoring sub-stations are installed on the large and small poles on both sides of the central main tower to monitor the large and small side conductors' ice load, the inclination angle of the insulator string and the conductor temperature, and transmit the monitoring information to the ZigBee network. Monitoring main extension: The monitoring main extension is installed on the central main tower, which mainly completes the monitoring of on-site images, micro-meteorology (environmental temperature and humidity, wind speed, wind direction, rainfall, air pressure, etc.) and the central main tower wire icing load and insulator string inclination [7]. After collecting the monitoring data, preliminary calculations and image compression, they are transmitted to the monitoring centre via GPRS. The monitoring centre host uses the calculation model of equivalent icing thickness integrated by expert software, the automatic recognition algorithm of icing image, the calculation method of icing density and other algorithms to realize the accurate calculation of the equivalent icing thickness and density of conductors and judge the icing of transmission lines. According to the situation, the ice thickness warning information will be given in time, and relevant staff will be notified to take effective measures to prevent the occurrence of icing disasters. In addition, the device can be linked with the existing ice melting device of the power system to realize automatic monitoring of wire ice coating and automatic ice melting, which is of great significance for improving the reliability of the transmission line operation in the ice coating area.

The structural block diagram of the monitoring sub-extension is shown in Figure 3. It mainly includes the main control unit, power supply module, ZigBee communication module, wire temperature monitoring unit, tension sensor, insulator string inclination sensor, etc. The monitoring sub-extension power module also uses solar + battery Way of working. The wire temperature monitoring unit completes the wire temperature monitoring and is composed of a temperature sensor, power supply module, MCU, ZigBee, etc. Since it is installed on the side of the wire, its power supply adopts the method of wire mutual inductance to obtain energy.

![Figure 3. Structure diagram of monitoring sub-station](image)

The wire temperature information collected by the wire temperature monitoring unit is sent to the tower monitoring sub-extension main control unit through the ZigBee network, while the wire tension change and insulator string inclination information collected by the tension sensor and inclination sensor are transmitted to the sub-extension main control unit via RS485. The main control unit of the auxiliary extension can process signals such as wire temperature, wire tension change, and insulator...
string inclination angle, and send this information to the monitoring main extension via the ZigBee network according to the set time.

5. Conclusions
In this paper, a new type of on-line monitoring device for icing of transmission lines is designed. It adopts the structure of main extension + double auxiliary extension, adds 2 sets of force sensors and inclination sensors, and integrates wire temperature monitoring and icing image monitoring, which can realize 3 base towers. Comprehensive monitoring of wire icing. This article believes that the effect of PRTV in delaying ice coating is not obvious when severe icing occurs, and the ice flashover voltage of insulators coated with PRTV is lower than that of insulators without PRTV. Therefore, coating PRTV is not an effective anti-ice flashover measure. In addition, the use of V-strings or the interposition of increased climbing skirts and large-diameter aerodynamic insulators can effectively increase the ice flash voltage. This method is more practical in the design and transformation of transmission lines.

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