# Design and Research of Segmented Ice Melting System for 10 kV Distribution Network

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**Abstract.** The ice disaster which lasted for dozens of days in 2008 caused serious damage to China's power grid, and the existing ice melting system is difficult to meet all the ice melting needs. In order to solve the above problems, a new segmented AC ice melting system is developed in this paper. Firstly, the structure of segmented AC ice melting system is proposed, which can directly extract electricity from 10 kV lines to realize ice melting at the end of the line or multi-branch lines. Then, the principle of segmented ice melting system is analyzed, and the ice melting voltage, current and system capacity are defined. After that, the detailed electrical and geometric parameters of each part of the system are designed. Finally, the detailed melting scheme of the segmented melting system is developed. This study is of great significance to solve the icing problem at the end of the line and improve the economy and flexibility of ice melting.

**Keywords:** Ac ice melting system · Sectional type · Ice melting scheme

## 1 Introduction

China has a vast territory, which is located in the middle latitudes, and the climate is humid, which leads to the icing of transmission lines in winter. According to statistics, in the severe ice and snow disasters that occurred in 2008, the icing period of the lines lasted for dozens of days, resulting in more than 30,000 power outages across the country, and power outages occurred in more than 100 cities and counties, resulting in serious economic losses and seriously affecting the quality of life of the people [1–3]. Therefore, how to solve the problem of line icing, improve the reliability of power supply and reduce the occurrence of tower breakage accidents is a key research direction at present [4–6].

Aiming at the problem of transmission line icing, scholars at home and abroad mainly carry out research in the fields of mechanical deicing, thermal deicing and so on. Due to the shortcomings of mechanical deicing, such as low melting efficiency, easy to damage wires and so on, there are many researches at present, and the more widely used deicing method is thermal deicing. The ways of thermal deicing include using laser irradiation to


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flow the wire to produce Joule heat and so on. On the one hand, laser irradiation requires large laser power, high-power laser device is difficult to develop, and low laser power will lead to low ice melting efficiency [7]. Therefore, the research of scholars at home and abroad mainly focuses on putting a large current into the transmission line, making the conductor produce joule heat, so as to realize the line deicing and deicing.

In the aspect of Joule thermal deicing, scholars mainly studied the fixed melting system and mobile melting system according to the arrangement and structure of the system. The fixed ice melting system is studied in reference [8–10], the composition of the system is studied and related tests are carried out in paper [8], and the ice melting experiments are carried out in paper [9, 10] based on the fixed ice melting system. However, the fixed ice melting system can only be built inside the substation and can only meet the ice melting needs of a certain substation. In order to solve the problem of multi-point icing, a large number of systems need to be arranged, and the economy is difficult to meet the requirements. In addition, part of the icing section is located at the end of the line, and the fixed ice melting system can not meet the ice melting demand. Literature [11–13] has carried out research on mobile ice melting system, which is deployed on large vehicles to solve the problem of ice melting in multi-point icing areas. However, the mobile ice melting system needs to be equipped with a special generator set to provide the power needed for ice melting, and the ice melting power supply occupies a large amount of volume of the whole system. According to the comprehensive research of scholars, there is still a lack of an economical ice-melting system and scheme that can meet the needs of multi-point ice melting.

In this paper, a segmented ice melting system is designed and studied, which takes electricity directly from the 10 kV distribution network and installs the system near the line that needs ice melting. No need to configure the power car, equipped with multiple groups of ice-melting short switch can realize the ice-melting of multiple lines. It not only solves the needs of multi-point ice melting and ice melting at the end of the line, but also improves the economy of ice melting and saves social resources.

## 2 Structure of Segmented Ice Melting System

The structure of the segmented ice melting system is shown in Fig. 1, which can be seen in Fig. 1. The segmented ice melting system consists of six parts, namely, multi-position ice melting transformer, measurement and protection unit, column switch, input isolation knife gate, output isolation knife gate and container shell.

10 kV transmission line, through the column switch, through the input isolation switch, connected with the multi-gear ice-melting transformer. The multi-gear ice-melting transformer is connected to the transmission line through the output switch. At this time, the end of the transmission line is short-connected to form an ice-melting current loop, and the current flows through the wire to produce joule heat to realize the ice melting of the transmission line. In this process, the measurement and protection unit monitors the voltage at both ends of the side of the multi-position ice-melting transformer and the current flowing through the side of the transformer in real time, and trips when overvoltage and overcurrent are detected to protect the multi-position ice-melting transformer.

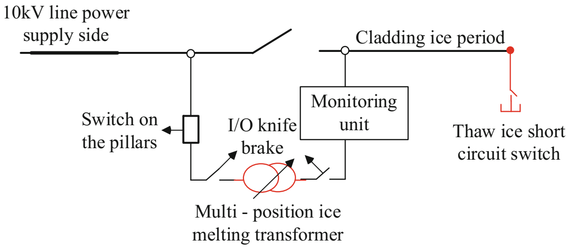


**Fig. 1.** Structure diagram of segmented ice melting system

## 3 Principle of Segmented Ice Melting System

The single-line equivalent circuit diagram of the segmented ice melting system is shown in Fig. 2. Figure 2 is a single line diagram, and the actual ice melting adopts three-phase AC melting. In Fig. 2, $U_0$ represents the primary input line voltage of the ice-melting transformer, $U$ represents the secondary output line voltage, $R$ represents the line resistance and X represents the line reactance.

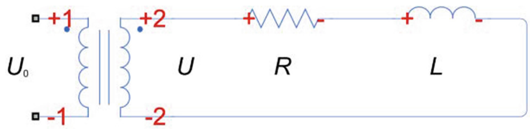


**Fig. 2.** Equivalent circuit diagram of segmented ice melting single wire

The multi-position ice-melting transformer takes electricity directly from the line, that is, the input voltage of the ice-melting transformer is the line voltage $U_0$ of the transmission line. Different transmission line conductors can withstand different ice-melting currents. Taking LGJ-70 as an example, the minimum ice-melting current is 290 A and the maximum ice-melting current is 420 A. At the same time, the unit resistance $Z_d$ of the wire can be known from the wire type, as shown in formula (1).

$$Z_d = R + jX \tag{1}$$

In formula (1), $R$ represents the resistance per unit length of the wire, and $X$ represents the reactance per unit length of the wire. According to the actual icing area, we can know the actual melting line length, recorded as $L$. The single-phase resistance $Z$ of the ice-melting circuit can be obtained, as shown in formula (2).

$$Z = L \cdot Z_d \tag{2}$$

According to formula (2) and the range of deicing current of the wire, the actual deicing voltage U can be selected.

When melting ice, the three-phase short connection at the end of the line is required, so the voltage added to each phase wire is the phase voltage of the line, from which the actual ice melting current $I_r$ can be obtained, as shown in formula (3).

$$I_r = \frac{U}{\sqrt{3}Z} \tag{3}$$

Furthermore, the required capacity $S$ of multi-position ice-melting transformer can be obtained, as shown in formula (4).

$$S = \sqrt{3}U \cdot I_r \tag{4}$$

## 4 Composition and Parameters of Segmented Ice Melting System

The detailed schematic diagram of the segment melting system is shown in Fig. 3. It can be seen from Fig. 3 that the structure of the segmented melting system is complex. The parameters of each component of the system are described below.

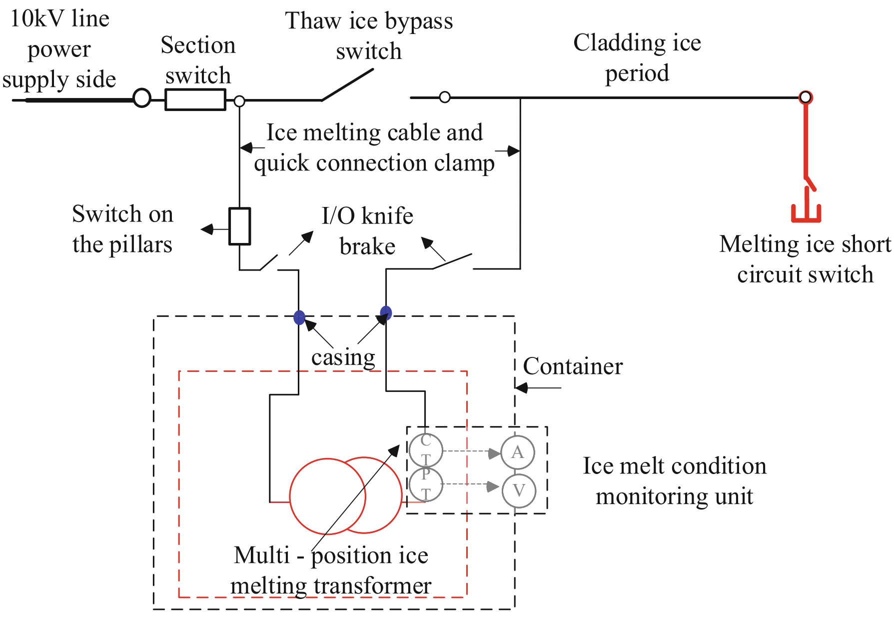


**Fig. 3.** Schematic diagram of segmented ice melting system

### 4.1 Parameter Design of Multi-position Transformer

Gear ice-melting transformer is the most important component in the segmented ice-melting system. The transformer gear is the most important parameter of the transformer, and the transformer gear takes into account the ice melting needs of each wire type. Therefore, it is necessary to calculate the minimum ice melting current and maximum ice melting current of each type of wire.

(1) **Analysis of minimum Ice melting current of conductor**

The calculation formula of the minimum melting current of wire is shown in formula (5).

$$I_{\min} = \sqrt{\frac{\Delta t}{R_0(R_{T0} + R_{T1})}} \tag{5}$$

In formula (5), $I_{\min}$ represents the minimum ice melting current (A); $R_0$ represents the resistance per unit length of the wire at 0 °C (Ω / m); $\Delta t$ represents the difference between the conductor temperature and the external temperature (°C), $R_{\mathrm{T0}}$ represents the equivalent ice conduction thermal resistance (°C·cm/W), and $R_{\mathrm{T1}}$ represents the equivalent thermal resistance of convection and radiation. The calculation formulas of $R_{\mathrm{T0}}$ and $R_{\mathrm{T1}}$ are shown in formula (6) and formula (7), respectively.

$$R_{T0} = \frac{\lg D/d}{273\delta} \tag{6}$$

$$\begin{cases} R_{T1} = \frac{1}{0.09D+0.22+0.73(VD)^{2/3}}(glaze) \\ R_{T1} = \frac{1}{0.04D+0.73(VD)^{3/4}}(rime) \end{cases} \tag{7}$$

In formula (6), $D$ represents the outer diameter of the iced wire (cm), d represents the wire diameter (cm), $\delta$ represents the thermal conductivity (W/cm °C), and in formula (7), $V$ represents the external wind speed (m). With the simultaneous formula (5)–(7), the minimum ice melting current can be obtained when the surface of the wire is 0 °C .

(2) **Analysis of maximum Ice melting current of conductor**

According to the national standard GB 50545-2010, the temperature rise of aluminum-clad steel strands should be in the range of +80 °C and 100 °C when the maximum carrying capacity is reached. In this paper, the intermediate value, that is, the temperature rise of the wire is 90 °C, is taken to calculate the maximum ice-melting current of the wire. In the simultaneous formula (5)–(7), the resistance in formula (5) is modified to the resistance of the wire at 90 °C, and the maximum ice melting current of the wire can be obtained by raising the temperature of the wire to 90 °C.

Based on the above results, the minimum and maximum ice melting current of each type of wire with ice thickness of 10 mm are calculated, as shown in Table 1.

**Table 1.** Minimum and maximum ice melting currents for different conductors

| Wire model | Minimum ice melting current (A) | Maximum ice melting current (A) |
|---|---|---|
| LGJ-35 | 200 | 300 |
| LGJ-50 | 230 | 350 |
| LGJ-70 | 290 | 420 |
| LGJ-95 | 360 | 520 |
| LGJ-120 | 420 | 600 |
| LGJ-150 | 480 | 600 |

Transformer capacity is designed as 2.1 MVA, rated input 10 kV. During the actual ice melting, the intermediate value of the minimum ice melting current and the maximum ice melting current of each wire is generally taken. According to Table 1, the output voltage of the transformer is designed as 2.4, 2.0, 1.6, 1.2, 1.0, 0.8 kV, with a rated current of 500 A, which can meet the ice-melting needs of distribution lines.

The scattered mode of the transformer is air-cooled, the transformer is equipped with a CT and a PT measurement, and corresponding to a group of passive voltmeters and ammeters to display the ice-melting output voltage and current in real time. The detailed design dimensions of the multi-position transformer are shown in Fig. 4. Structure size of transformer in Fig. 4: 2.0*1.3*2.2 m, weight 4.0 t.

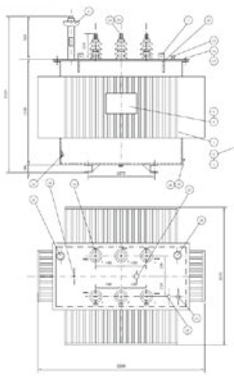

**Fig. 4.** Dimension design diagram of multi-position transformer

### 4.2 Parameter Design of Isolation Knife Gate

(1) the segmented ice melting system is equipped with a set of ice melting input isolation knife gate, a set of output knife gate, a set of bypass knife gate, a set of post switch (including secondary and external tripping function), 2 sets of ice melting short switch, a total of 5 knife gates, a set of on-column switches.
(2) switch rated voltage 10 kV, rated current 630 A.

### 4.3 Parameter Design of Ice-Melting Cable

(1) the segmented ice-melting system is equipped with a set of three-phase input cables and a set of three-phase ice-melting output cables.
(2) input the rated parameters of ice melting cable: input 10 kV, 200 A, single core, 50 m per phase of three phases.
(3) rated parameters of output ice-melting cable: input 6 kV, 600 A, single core, 50 m per phase

### 4.4 Parameter Design of Ice-Melting Voltage and Current Measurement Protection Unit

The ice-melting voltage and current measurement protection unit mainly detects the ice-melting voltage and ice-melting current, and automatically records the relevant data curve. The fault signals such as overvoltage and overcurrent are integrated and sent to the post switch for protection as a tripping signal. At the same time, the ice melting state can be uploaded to the remote master station, which is convenient for other off-site personnel to check the ice melting status in real time through communication software.

All the above devices are integrated into the container to reduce the damage caused by the external environment to the ice-melting equipment, and the arrangement of the ice-melting parts in the centralized box is shown in Fig. 5.

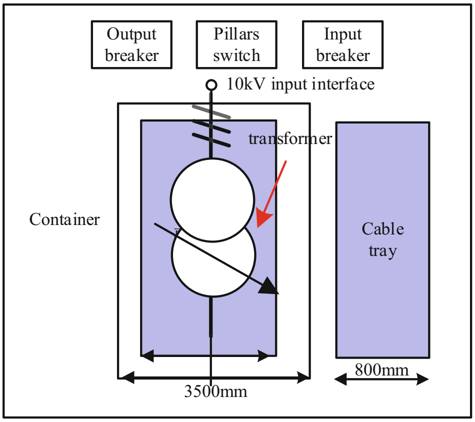


**Fig. 5.** Layout of ice-melting components

## 5 Ice Melting Scheme of Segmented Ice Melting System

Taking the 10 kV transmission line in a certain area as an example, after on-site investigation, the wire parameters of the transmission line are shown in Table 2.

**Table 2.** Conductor parameters of transmission lines

| Wire model | Ice line length (km) | Wire resistance per unit length (Ω/km) | Unit length wire reactance (Ω/km) | Ice melting access point | Ice melting short contact |
|---|---|---|---|---|---|
| LGJ-70 | 4.7 | 0.408 | 0.569 | No. 1 tower | No. 45 tower |

According to the parameters in Table 1, the total impedance of ice melting line is calculated by simultaneous formula (1) and formula (2).

$$Z = 4.7 \times (0.408 + 0.569j) = 2.676\Omega \tag{8}$$

The transformer gear is 1600 V, the formula (8) is substituted for (3), and the ice melting current is calculated to be

$$I_r = \frac{1600}{\sqrt{3} \times 2.676} = 345\ \text{A} \tag{9}$$

By substituting formula (9) for (4), the capacity of multi-position ice-melting transformer is obtained.

$$S = \sqrt{3} \times 1600 \times 345 = 957\,\text{kVA} \tag{10}$$

According to the above calculation results, the line ice melting scheme can be established as follows:

(1) A branch line of a certain line adopts a segmented AC ice melting system, the voltage gear of multi-gear transformer is 1600 V, and the ice melting mode adopts three-phase AC ice melting.
(2) When melting ice, it is necessary to disconnect all transformers connected to tower $1 \times 45$, including special transformers installed by users themselves.
(3) The ice-melting switch is installed on the No. 45 tower. When melting ice, it is necessary to manually operate the short switch to complete the three-phase short connection of the line. The actual wiring diagram is shown in Fig. 6.

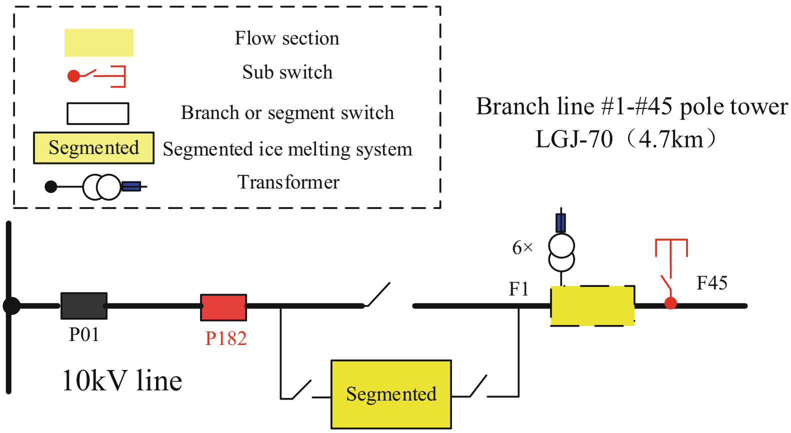


**Fig. 6.** Actual ice melting wiring diagram of the line

(4) blackout range: all stations connected to tower 1: 45.
(5) during the ice melting period, the temperature rise of the bare wire was measured at Tower 1 and Tower 45 respectively to ensure that the temperature rise was less than 90 °C.
(6) after melting ice, close the transformers in all the stations connected to the line, and finally restore the power supply to the line.

## 6 Conclusion

A new type of AC ice melting system is studied in this paper. For the segmented ice melting system, the structure, ice melting principle, equipment, parameters and ice melting scheme of the ice melting system are studied. The main conclusions are as follows:

(1) the segmented AC ice melting system takes electricity directly from the line and is installed near the icing area, and the multi-branch ice melting of the transmission line can be realized directly by regulating the voltage of the multi-gear transformer. The utility model has the advantages of convenience, rapidity and economy.
(2) the segmented AC ice melting system is mainly composed of multi-gear transformer, isolation switch, ice melting cable, measurement and protection unit and container. The electrical and geometric parameters of each component are studied in detail.
(3) the ice melting principle of segmented AC ice melting system is studied, and the ice melting current, ice melting voltage and system capacity are determined. And the detailed implementation plan of ice melting is worked out in turn.

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