# THE DESIGN PRINCIPLE OF ANTI-ICING INSULATOR BASED ON SWITCH EFFECT AND GRADUAL CHANGE OF BUSHING SURFACE RESISTIVITY

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***Abstract***: The appearance of glaze frost brings in serious problem of ice accumulation in the grid, even lead to collapse of tower. Until now, there is no effective way to prevent icing on the surface of insulator and thus it is of necessity to design a new type of anti-icing insulator. This paper is concerned with the design principle of anti-icing insulator with switch effect, which can be energy-saving method. Thermodynamic model was presented to find out influence factors of anti-icing. According to the experiment, conclusion can be drawn that the degree of de-icing is closely related to the leakage current. With current less than 1mA, no obvious effect exists and Leakage current larger than 10mA was required. The experiment also proved that position and band of switch are also of vital importance.

## 1. INTRODUCTION

Glaze frost always happen during early spring in south China, especially in north Guangdong and south Huna n. With the high humidity and low temperature at this time, there exist a lot of super-cooling water. The freezing rain landing on the surface of insulator will gradually abridge the gap between the bushings adjacent even lead to collapse of tower. Recently many methods are applied to icing problem both in domestic and aboard, including mechanical de-icing and natural shedding, which belong to passive measures. But until now, there is no active way to prevent icing on the surface of insulator and thus it is of necessity to design a new type of anti-icing insulator. During the investigation in serious icing regions, certain anti-icing performance was discovered in the semi-conductive glazed insulators. With lower surface resistivity, leakage current is more significant than ceramic, glass or composite insulators during operation and thus the heat generated makes the ice melting profitable. Definitely the energy cost of such de-icing method is enormous. The design of anti-icing insulator is based on the principle of semi-conductor glazed insulators, but with less energy consumption. Electro-thermal effect and switch effect were both applied to our experiment. Under normal operation, high surface resistivity of bushing layers ensures the leakage is small enough to save energy. During icing process, ice water mixture on the switch band can be connected to lower surface, which has smaller surface resistivity, to generator heat, which makes anti-icing and energy-saving possible.

## 2. RESULTS AND DISCUSSION

The performance of anti-icing is determined by the value of leakage current to a great extent. When the leakage current is less than 1mA, anti-icy performance is not obvious. According to thermodynamic model, current larger than 10mA makes anti-icy possible. In addition, switch position and bandwidth are important factors to achieve the goal. Switch band located near earth terminal can improve reliability and make the ice water mixture conduct rapidly, but partial discharge always happen in this area due to serious electric field distortion. Although Switch band located in intermediate bushings did not meet our expectations, this kind of design is more feasible, which makes electric field distribution uniform thus lead to flashover voltage improvement. Furthermore, switch band located around outer diameter of rod can still provide reliability.

## 3. CONCLUSION

(1) Value of leakage current is crucial factor for anti-icy performance. The length of icicle reduced with current rising up, but current less than 1mA cannot achieve ultimate purpose.
(2) Switch position and bandwidth are impact factors, and should be located around the outer diameter of intermediate bushings.
(3) Switch band located near the earth terminal lead to high intensity partial discharge, thus accelerate the aging of composite material.

## 4. REFERENCES

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# The Design Principle of Anti-icing Insulator Based on Switch Effect and Gradual Change of Bushing Surface Resistivity

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***Keywords-icing; insulator; leakage current; electric field; switch effect***

## I. INTRODUCTION

Glaze frost always happen during early spring in south China, especially in north Guangdong and south Hunan. With the high humidity and low temperature at this time, there exists a lot of super-cooling water. The freezing rain landing on the surface of insulator will gradually abridge the gap between the bushings adjacent even lead to collapse of tower. Recently many methods are applied to icing problem both in domestic and aboard, including mechanical de-icing and natural shedding, which belong to passive measures. But until now, there is no active way to prevent icing on the surface of insulator and thus it is of necessity to design a new type of anti-icing insulator. During the investigation in serious icing regions, certain anti-icing performance was discovered in the semi-conductive glazed insulators. With lower surface resistivity, leakage current is more significant than ceramic, glass or composite insulators during operation and thus the heat generated makes the ice melting profitable. Definitely the energy cost of such de-icing method is enormous. The design of anti-icing insulator is based on the principle of semi-conductive glazed insulators, but with less energy consumption. Electro-thermal effect and switch effect were both applied to our experiment. Under normal operation, high surface resistivity of bushing layers ensures the leakage is small enough to save energy. During icing process, ice water mixture on the switch band can be connected to lower surface, which has smaller surface resistivity, to generator heat, which makes anti-icing and energy-saving possible.

## II. THERMODYNAMIC MODEL OF ANTI-ICING

Surface temperature of insulator can be kept above freezing point with sufficient heat to prevent or reduce ice accumulation. As mentioned above, switch band works when cooling water arrived on the surface. According to thermodynamic model, the relationship can be found between leakage current and thickness of ice layer, as well as how switch band and resistivity influence the effect of anti-icing.

One-dimensional solidification process of cooling water on the surface of insulator was applied, as shown in figure 1.

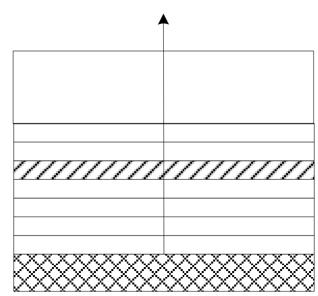

Fig.1 schematic diagram of solidification

Assuming constant temperature of liquid and non-uniform of solid temperature, equation of heat conduction was satisfied:

$$\frac{\partial T_S}{\partial t} = K_S \frac{\partial^2 T_S}{\partial z^2}, 0 < z < h \qquad (1)$$

In the interface z=h, temperature field meet boundary conditions:

a. Temperature continuous condition, $T_L = T_S = T_M$;

b. Heat conservation condition, $\Delta H \cdot \partial h/\partial t = k_s \cdot \partial T_S/\partial z$;

The energy of ice melting can be divided into two parts, energy absorbed to rise up ice temperature to freezing point before phase transformation and latent heat of phase change.

$$Q_1(h) = C_{ice} \cdot d_{ice} \cdot S \cdot (T_M - T_B) \cdot h/2 \qquad (2)$$

$$Q_2(h) = \alpha \cdot d_{ice} \cdot S \cdot h \qquad (3)$$

According to leakage current, heat generated can also be determined as following:

$$I(t)=\frac{U}{R_{semicon}+\rho_{mix}\ln(r_2/r_1)/(2\pi h)} \quad (4)$$

$$Q_0(h)=\frac{U^2\Delta H}{K_S(T_M-T_B)R_{semicon}}[\frac{1}{2}(h^2-h_0^2)-\frac{\rho_{mix}\ln(r_2/r_1)}{2\pi R_{semicon}}(h-h_0)+\frac{\rho_{mix}^2\ln^2(r_2/r_1)}{4\pi^2R_{semicon}^2}\ln\frac{h+\rho_{mix}\ln(r_2/r_1)/(2\pi R_{semicon})}{h_0+\rho_{mix}\ln(r_2/r_1)/(2\pi R_{semicon})}] \quad (5)$$

In that,

$C_{ice}$--Specific heat capacity;
$d_{ice}$--density of ice;
$S$--surface area of insulator;
$T_M$--condensation temperature of water;
$T_B$--surface temperature of insulator;
$h$--thickness of ice layer;
$\alpha$--latent heat coefficient per unit quality;
$\rho_{mix}$--conductivity of ice water mixture;
$U$--applied voltage;
$K_S$--thermal diffusion coefficient;
$\Delta H$-- latent heat coefficient per unit volume;
$h_0$--initial thickness of ice layer due to nuclei;
$R_{semicon}$--resistivity of semi-conductive layer;
$r_2$,$r_1$--out and inner diameter of cricoid switch band;
$k_s$--coefficient of heat conduction.

In order to effectively prevent icing, thus,

$$Q_0(h)\geq Q_1(h)+Q_2(h) \quad (6)$$

According to the analysis above, appropriate resistivity, position and bandwidth of switch should be determined deliberately to achieve the best.

## III. EXPERIMENTAL CONDITION AND FACILITY

Icehouse with controllable temperature, gas-liquid spraying system, measurement and monitor system, as well as AC test system is included in the artificial climate chamber. As shown in Fig.2, the test object was hung up in the climate chamber, with isolated insulator as protector and weight sensor to monitor the ice concentration. Nozzles are located on one side. The ice growth and leakage current are real-time monitored by camera and computer.

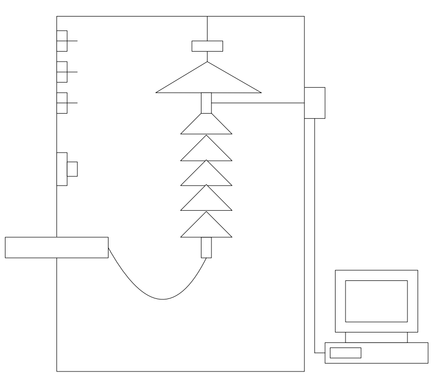

Fig.2 Climate chamber for icing experiment

Water spray system is consist of nozzle, water pump and air compressor, controlled by PLC (Programmable Logic Controller). Dual fluid atomizers were chosen to make mist with smaller diameter possible. Fig.3 shows control system diagram of water spray device.

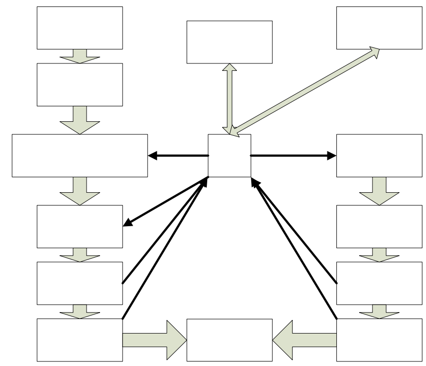

Fig.3 Control system diagram of water spray device

According to field data collected, experimental parameters are set as follows, shown in table 1.

Table1 Experimental Condition

| Parameters | Value |
|---|---|
| Diameter of water droplet | 25-35μm |
| Water flow | 0.129 l/min |
| Conductivity of water | 100 μs |
| Spray angle | 80° |
| Ambient temperature | -6℃ |

## IV. EXPERIMENT RESULTS

Leakage current is determined by switch location and resistivity of semiconductor. In our experiment, 35kV composite insulator with different surface resistivity was tested. For the sake of smaller space between adjacent bushing, switch band were set around the outer diameter to improve the reliability, which makes ice water mixture conduct easier. Leakage current and photos of three different samples were recorded.

### *A. Ordinary composite insulator*

Ordinary composite insulator was tested as reference for comparison. After 1 hour of icing with 20.2kV energized, icicle was obvious with the length of 60mm and small ice particles were found on the upper surface of bushing, but around rod no ice area exists, as shown in figure 4.

Fig.4 icing experiment of composite insulator

During the experiment, data of leakage current were monitored in real time. From the trend curve, leakage current was maintained at low level, with maximum value of 0.22mA and average value of 0.07mA, as shown in figure 5. Thus the corresponding heat generated is not sufficient to make the ice or icicle melt.

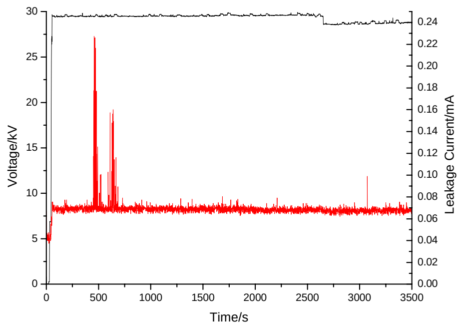


Fig.5 trend of leakage current for sample one

### B. *Switch band located in intermediate bushings*

As mentioned in thermodynamic model, leakage current with higher value may lead to further improvements. Thus semi-conductive materials were applied to lower resistivity. Figure 6 shows the second experiment sample, with switch band of 20mm width located in intermediate bushings (red part in figure 6), while the other are made of semi-conductor.

Fig.6 the second test sample

After 1 hour continuous experiment, icicles with maximum value of 51mm (less than sample one) and small ice pellets still appeared on the surface of insulator. Figure 7 shows the state of icing.

Fig.7 icing experiment of the second sample

As shown in figure 8, the value of leakage current varied from 0.8mA to 1.2mA on the whole. Partial discharge happen occasionally during experiment. Although the leakage current has rised up to 1mA and the length of icicle reduced compared with the first sample, anti-icy effect was not fully achieved.

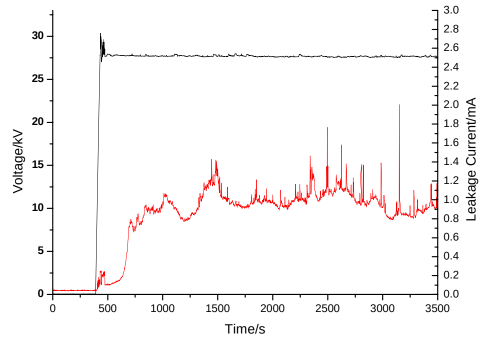


Fig.8 trend of leakage current for sample two

### C. *Switch band located in bushing adjacent to earth terminal*

In order to improve reliability and make ice water mixture conduct rapidly, the third sample with switch band located in bushing adjacent to earth terminal was tested, as shown in figure 9.

Fig.9 the third test sample

During the experiment, small arc appeared on the rod near earth teminal. For the sake of safty, the experiment was suspended seven minute latter. Figure 10 shows the slender discharge trace along the rod.

Fig.10 discharge trace along the rod

As can be seen from the data of leakage current recorded, value of current started to increase significantly 4 minutes later. High intensity partial discharge turned into small arc 6 minutes later and current had rise up to nearly 10mA. Figure 11 shows the trend of leakage current for the third sample.

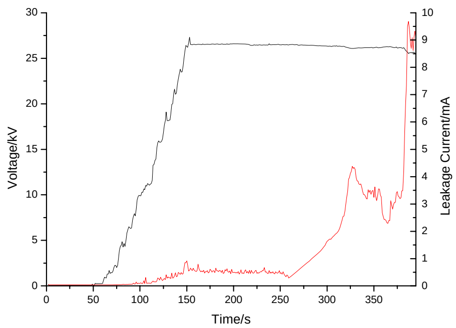


Fig.11 trend of leakage current for sample three

## V. DISCUSSION AND CONCLUSION

The performance of anti-icing is determined by the value of leakage current to a great extent. When the leakage current is less than 1mA, anti-icy performance is not obvious. According to thermodynamic model, current larger than 10mA makes anti-icy possible. In addition, switch position and bandwidth are important factors to achieve the goal. Switch band located near earth terminal can improve reliability and make the ice water mixture conduct rapidly, but partial discharge always happen in this area due to serious electric field distortion. Although the second sample did not meet our expectations, this kind of design is more feasible, which makes electric field distribution uniform thus lead to flashover voltage improvement. Furthermore, switch band located around outer diameter of rod can still provide reliability. From the experiments above, conclusion can be drawn as follows:

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