SWITCHING EFFECT OPTIMIZATION OF INSULATOR'S ANTI-ICE SEMI-CONDUCTIVE RTV COATING

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***Abstract**:* Semi-conductive room temperature vulcanized silicone rubber coating (SCRTV) with electro thermal effect is effective in preventing ice on insulators, but it has side effects. In this paper, ANSYS models are established to find the optimized switching effect structure to overcome the side effects. And proper resistivity of SCRTV is selected using PSCAD simulation. In the end, the structure and resistivity are tested experimentally. The result shows that the leakage current curve is as predicted and that very little ice is accumulated.

1. INTRODUCTION

Through the decades researchers developed several anti-icing methods that can be classified into electro thermal, mechanical, chemical and kinetic techniques [1]. Electro thermal technique generally utilizes a semi-conductive room temperature vulcanized silicone rubber coating (SCRTV) on the insulators to produce heat so as to prevent the ice formation [2]. However, in the long term, the conductivity of SCRTV can be fatal because it causes larger leakage current that may lead to lower flashover voltage and higher energy loss.

The coating structure with switching effect of SCRTV is designed by Prof. Jia and his research group to solve this problem [3]. The core idea of switching effect structure is to divide the SCRTV coating into two consecutive areas separated by RTV belt. In the warm weather, the semi-conductive areas are not continuous, so the leakage current remains at a low level; but when the ice forms on the surface of insulator, the RTV belt is bridged by ice water mixture with certain conductivity, and the conductive areas become continuous, thus the leakage current increases and starts to produce heat.

In this paper, several coating structures with switch effect are analysed and simulated in ANSYS. After that, electric fields corresponding to different width and different positions of RTV belt are compared to find a relatively reasonable structure scheme. Under optimized coating structure, a mathematical model of insulator string is introduced and simulated in PSCAD to select a proper SCRTV resistivity. In the end, the chosen coating structure and SCRTV resistivity are tested in a specially designed climate room.

2. RESULTS AND DISCUSSION

Surface electric field distribution is in Fig. 1. The down positioned RTV belt (width=15mm) causes the smallest surface electric field, which is even lower than insulators without any coating.

Relationship between leakage current and resistivity of SCRTV is shown in Fig. 2. The water conductivity σ makes little difference because when σ is high enough, the impedance depends on resistance of SCRTV layers.

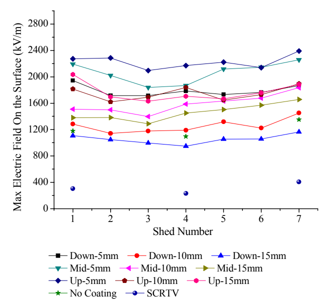

Figure 1: Max surface electric field of sheds

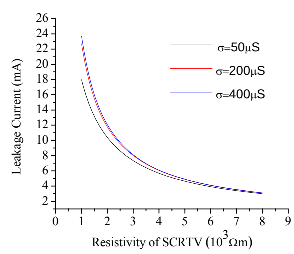

Figure 2: Relationship between leakage current and resistivity of SCRTV

3. CONCLUSION

Optimized coating structure with switching effect is down positioned RTV belt (width=15mm). The leakage current when BRK is closed has to be about 10mA, as a result, ρ=2×103Ω□m is selected. Experimental test shows good concordance.

4. REFERENCES

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***Abstract*—Semi-conductive room temperature vulcanized silicone rubber coating (SCRTV) with electro thermal effect is proved to be effective in reducing ice accumulation on insulators. In order to overcome the shortcomings brought by the relatively high conductivity of this coating, a coating structure with switching effect was proposed. In this paper, ANSYS models are established to find the optimized switching effect structure scheme through comparison. Also, proper resistivity of SCRTV is selected using PSCAD simulation. In the end, the structure and resistivity are tested experimentally in a climate room designed for this, the result shows that the leakage current curve is generally as predicted and that very little ice is accumulated.**

Keywords: switching effect optimization; semi-conductive RTV coating; anti-ice; insulators

I. INTRODUCTION

Ice accumulation on insulators in the winter has been a serious problem for power system for many years. Through the decades researchers developed several anti-icing methods that can be classified into electro thermal, mechanical, chemical and kinetic techniques [1]. Among these techniques, electro thermal technique is the most effective one with the least complexity and manpower demand. It usually utilizes a semi-conductive room temperature vulcanized silicone rubber coating (SCRTV) on the insulators to produce heat so as to prevent the ice formation [2]. However, in the long term, the conductivity of SCRTV can be fatal because it causes larger leakage current that may lead to lower flashover voltage and higher energy loss.

The coating structure with switching effect of SCRTV is designed by Prof. Jia and his research group to solve this problem [3]. The core idea of switching effect structure is to divide the SCRTV coating into two consecutive areas separated by RTV belt. In the warm weather, the semi-conductive areas are not continuous, so the leakage current remains at a low level; but when the ice forms on the surface of insulator, the RTV belt is bridged by ice water mixture with certain conductivity, and the conductive areas become continuous, thus the leakage current increases and starts to produce heat.

It can be inferred that the RTV belt's position is related to the performance of switching effect as well as possible side effects and that the leakage current surely has something to do with the resistivity of SCRTV. The above-mentioned two points are still not very clear. In this paper, several coating structures with switch effect are analyzed and a 2D model in ANSYS based on finite element method is established to calculate the electric field distribution. After that, electric fields corresponding to different width and different positions of RTV belt are compared to find a relatively reasonable structure scheme. To select a proper SCRTV resistivity under optimized coating structure, a mathematical model of insulator string is introduced and simulated in PSCAD. In the end, the chosen coating structure and SCRTV resistivity are tested in a specially designed climate room.

II. COATING STRUCTURE OPTIMIZATION

A. Possible Coating Structures

Fig. 1 basically shows the coating structure designed with switching effect. The RTV belt is designed to be bridged by the ice, so it should be at places where the ice frequently accumulates. There are three possible positions for the RTV belt, i.e. up, mid and down.

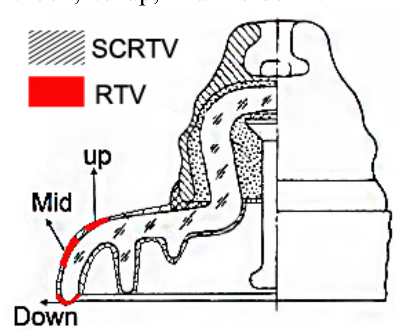

Figure 1. Three possible coating structures

When evaluating performances of the three possible positions the most important rule is the surface electric field of insulator has to be small and uniform. Besides the positions, the width of RTV belt is also an important factor

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that affects electric field distribution. Considering the thickness is hard to control in practice, in this research thickness is assumed to be 1mm, which is an approximate number of that in real situation.

B. Electric Field Simulation

Although the insulator string works under alternating voltage, the electric field around it can be considered stable, because the wave length of alternating voltage is much longer than the length of the insulator string. Also the leakage current is very small under normal condition, so electrostatic field can be used to research into electric field distribution of insulator string. Considering the symmetry of insulator string, a 2D model is built in ANSYS which consists of 7 pieces of XP-160 insulators. The different materials in the insulator string are differentiated by relative dielectric constants which are shown in Tab. 1.

TABLE I. RELATIVE DIELECTRIC CONSTANTS OF MATERIALS

Materials	air	porcelain and concrete	metal and SCRTV	RTV
Relative Dielectric Constants	1	6	60000	3

The transmission lines and corona are not considered in the model, and the thickness of air around the insulator is set as 3m. The voltage applied is the peak value of phase-ground voltage of 110kV system, which is 89.8kV. As mentioned above, the thickness of coating is 1mm, and in this model variables are the width and positions of RTV belt, the width considered in the simulations are 5mm, 10mm and 15mm, respectively.

C. Results and Discussion

Fig. 2 shows the maximum surface electric field of every single shed in the insulator string. Shed 1 is at the bottom of insulator string and shed 7 is at the top. The strength of surface electric field is closely related to partial discharge, and a low and uniform surface electric field is helpful to increase the flashover voltage of insulator string. Fig.2 indicates that when the insulators are covered with continuous SCRTV (without RTV belt), the surface electric field is around 400kV/m, which is the lowest one. This is because the continuous SCRTV works as an electric field shield layer. Actually, this structure is proved to be unacceptable because of its continuous large leakage current. Also, the up positioned RTV belt brings the largest surface electric field and the down positioned RTV belt causes the lowest surface electric field. The width of RTV belt also affects strength of electric field. The wider the RTV belt is, the lower the surface electric field is.

The lowest surface electric field structure is the downed position RTV belt with the width of 15mm, and its maximum surface electric fields of 7 sheds are all below 1200kV/m. It should be noted that electric field of this structure is even lower than that of insulators without any coating.

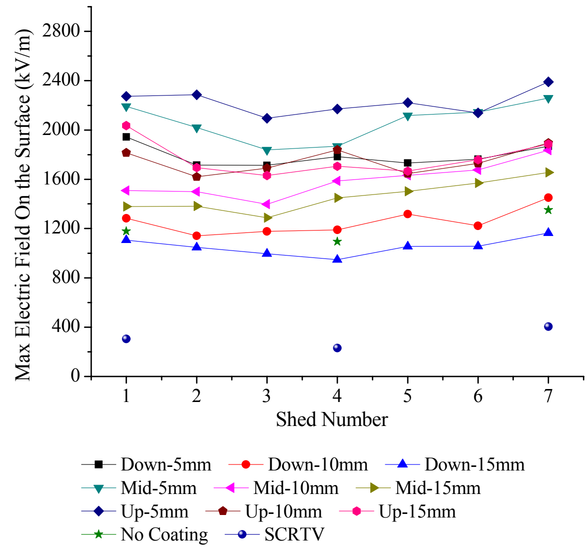

Figure 2. Max surface electric field of sheds

III. SCRTV RESISTIVITY SELECTION

A. Equivalent Circuit and Parameters

The down positioned RTV belt with the width of 15mm shown in Fig. 3 is the most reasonable structure. SCRTV resistivity selection is based on this structure.

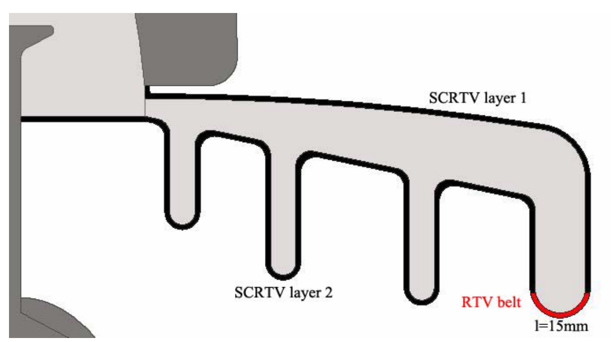

Figure 3. Optimized coating structure with switching effect

It is proved in the laboratory that leakage current around 10mA basically meets the anti-ice demand [4]. So the SCRTV's resistivity has to be selected to control leakage current at about 10mA with consideration of other factors like resistivity of water and ice mixture on the surface and possible capacitance between SCRTV layers. As is mentioned above, the layer's thickness is 1mm, which is not a variable here.

Fig. 4 is the equivalent circuit of one shed, the complete simulation in PSCAD includes 7 circuits like this in series. C_1 is the capacitance metal fittings of insulator; R_C is the resistance of porcelain; C_2 is the capacitance between

SCRTV layer 1 & 2; R_W is the resistance of bridging water and ice mixture, which is a variable.

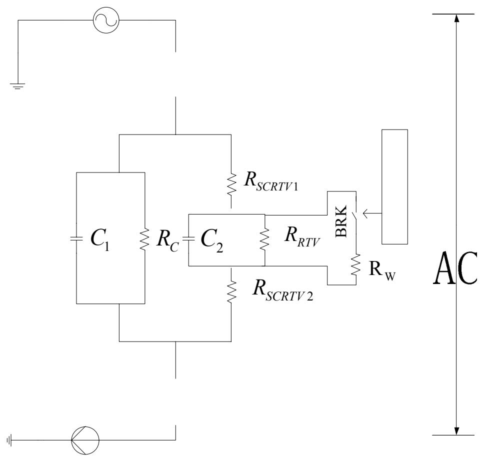

Figure 4. Equivalent circuit of optimized coating structure

The applied voltage is phase to ground voltage of 110kV system, U=63.5kV; R_C=4000MΩ; C_1=40pF.

The diameter of XP-160 insulator is 255mm, thus the RTV belt can be simplified as a ring with inner radius r_1=120mm and outer radius r_2=127.5mm. According to national standard, resistivity of RTV should be larger than 10^{14}Ω·m, here ρ=10^{14}Ω·m. The thickness D is 1mm. So the resistance of RTV belt is

$$R_{RTV}=\int_{r_1}^{r_2}\frac{\rho dr}{2\pi rD}=\int_{0.12}^{0.1275}\frac{10^{14}dr}{2\pi r10^{-3}}=9.6\times10^{14}\Omega \tag{1}$$

SCRTV layer 1 is also a ring, whose inner radius is 53.5mm and outer radius is 127.5mm. Resistivity of SCRTV is variable ρ_{sc}.

$$R_{SCRTV1}=\int_{r_1}^{r_2}\frac{\rho dr}{2\pi rD}=\int_{0.0535}^{0.1275}\frac{\rho dr}{2\pi r10^{-3}}=138\rho_{sc}\Omega \tag{2}$$

Creepage distance of SCRTV layer 2 is 3.1 times that of SCRTV layer 1, hence we do an approximate treatment,

$$R_{SCRTV2}=3.1R_{SCRTV1}=428\rho_{sc}\Omega \tag{3}$$

Capacitance exists between SCRTV layer 1& 2, virtual area of is capacitor is the difference of area of the shed and its metal fittings. Distance between two layers is d=15mm.

$$C_2=\frac{\varepsilon S}{d}=\frac{6\times8.85\times10^{-12}\times\pi(0.1275^2-0.0535^2)}{0.015}=148pF \tag{4}$$

Similar to (1), R_W can be expressed in (5). σ is the conductivity of water and ice mixture.

$$R_W=\int_{r_1}^{r_2}\frac{dr}{2\pi r\sigma D}=\int_{0.12}^{0.1275}\frac{dr}{2\pi r\sigma10^{-3}}=\frac{9.6}{\sigma}\Omega \tag{5}$$

In the warm and fine weather, the RTV belt is not bridged, that means BRK in Fig. 4 is open. And once the RTV belt is bridged by ice and water mixture in cold weather, BRK is closed.

B. Results and Discussion

Consider about leakage current when BRK is closed first. The leakage current is related to σ and ρ_{sc}, the conductivity of precipitation water ranges from 50μS to 400μS in China depending on territories, how the leakage current varies with ρ is presented in Fig. 5.

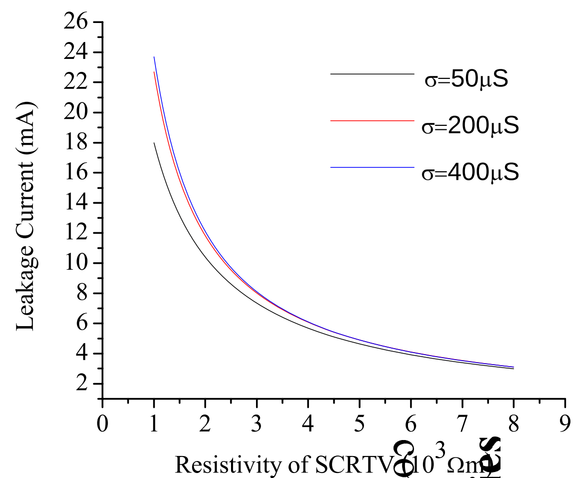

Figure 5. Relationship between leakage current and resistivity of SCRTV

Leakage current varies inversely as ρ, and the water conductivity makes little difference especially when it is relatively high. This is because when σ is high enough, the impedance depends on resistance of SCRTV layers. The leakage current when BRK is closed has to be about 10mA, as a result, ρ=2×10^3Ω·m is selected.

When BRK is open, the leakage current is very low, because resistance of RTV belt is almost 10^{10} times that of SCRTV, even if the width of RTV belt is only 15mm. Actually, when BRK is open (in the warm and fine weather), the leakage current is as low as 0.7mA according to simulation, which is satisfactory.

IV. EXPERIMENTAL TEST

The optimized coating structure has a relatively low surface electric field and selected resistivity of SCRTV provides proper leakage current holding back the ice formation. They still need to be tested, as well as whether the switching effect can really take place.

A. Facilities and Parameters

The test is carried out in climate room in CEPRI, Beijing. The climate room has 4m diameter and 7m height, and the temperature can be controlled from -20℃ to 40℃. Fig. 6 is the inner structure of this climate room. It is able to simulate the natural ice accumulation process by spraying super cooled water droplets.

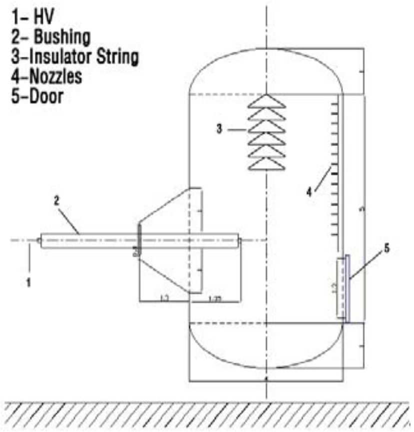

Figure 6. Structure of climate room

The experiment is divided into 3 groups, group A is insulators covered with optimized coating structure, see Fig. 3, group B is insulators covered with continuous SCRTV (without RTV belt), and group C is insulators without any cover.

Firstly, cool down the climate room to -8℃, then start to eject super cooled water at 70l/h (spaying 15s every 120s). Conductivity of ejected water is 400μS, and 63.5kV alternating voltage is applied from the beginning. Experiment lasts 4 hours.

B. Results

Fig. 7 is the ice accumulation results of three groups after 4 hours' time. Group A and B shows satisfactory effect of preventing ice accumulation.

Figure 7. Result of ice accumulation test

However, the leakage current curves of group A and B are different, see Fig. 8. Leakage current of group A can vary with the quantity of ice on insulator's surface, but leakage current of group B remains at a very high level. High leakage current can produce heat to eliminate ice, yet it also causes energy waste and weakens insulation performance. Structure that can adjust leakage current adaptively as designed in this paper is more satisfactory.

The experimental test end up with good result, the optimized structure and the selected SCRTV resistance are acceptable.

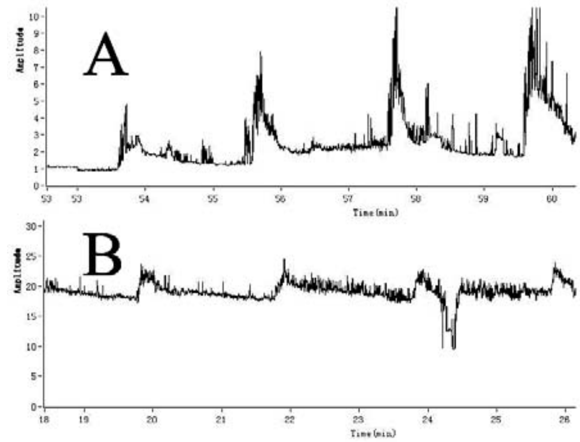

Figure 8. Leakage current of group A & B

V. CONCLUSION

RTV belt inserted into the SCRTV cover is an effective structure with switching effect which can change leakage current adaptively according to the ice accumulated on insulators.

The optimized structure is down positioned RTV belt whose width is 15mm. Based on this structure, SCRTV resistivity should be around $2\times10^3\Omega\cdot$m. Experimental test shows good performance of the structure and the parameter proposed in the simulation.

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