ANALYSIS OF THERMAL DISTRIBUTION ALONG INSULATOR WITH SEMICONDUCTING RTV

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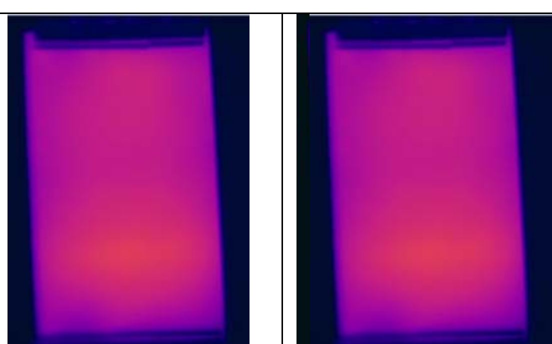
***Abstract**:* Icing problems led a great damage to the power network over the world recent years and a lot of ways dealing with this problem are proposed. Semiconducting RTV coating applied to insulators is first put forward in 2007 and it makes a significant role in defeating the ice accretion on insulator surface. It's main advantage in anti-icing are combination of hydrophobicity and hydrophobicity transfer based on the ordinary RTV and the Joule heating effect created by the leakage current. This paper focus on the heat effect of the semiconducting RTV applied to suspension insulator during freezing condition. The thermal distribution along the insulator string with semiconducting RTV coating applied with service voltage in cold condition is investigated using an infrared FLIR. Results showed that the range of the resistance of the semiconducting RTV coating being 1~10 MΩ can get a suitable temperature rise.

1. INTRODUCTION

Atmospheric icing affects a wide variety of structures in power network in many countries. It is well known to occur in China in winter 2008. And coating semiconducting RTV on insulator is an effective method in anti-icing [1]. In this paper, the heating effect is studied in glass specimens with the surface coating of semiconducting RTV in both surfaces using thermal balance theory. And the temperature rise and distribution are monitored on the insulator with semiconducting RTV.

2. RESULTS AND DISCUSSION

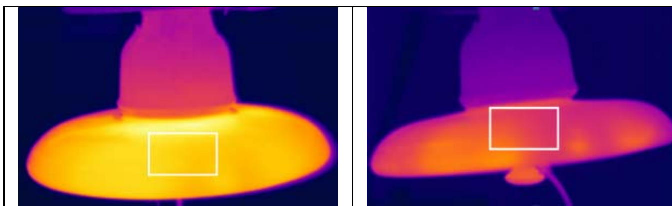
According to the thermal balance theory, the range of the resistor of the semiconducting RTV on glass sample is determined to be 0.1~1 MΩ as shown in Figure.1.



Ambient temperature: 15 ºC	Ambient temperature: -11ºC
Specimen temperature : 26 ºC	Specimen temperature : -4ºC

Figure.1: Temperature rise in 15 ºC and -10 ºC

As the semiconducting RTV is coated on single IEEE standard insulator at different resistance and variable applied voltage, a significant effect of temperature rise is obtained not only at room temperature but in cold condition just as Figure.2 shown. In the end, the scale of the resistor is corrected to be 1~10 MΩ.



Voltage(kV)	2.11	**Voltage(kV)**	0.94
Leakage current(mA)	11.56	**Leakage current(mA)**	11
Ambient temperature(ºC)	18	**Ambient temperature(ºC)**	-6
Sample temperature (ºC)	24	**Sample temperature (ºC)**	19

Figure.6: Temperature rise of insulator in 18 ºC and -6 ºC

3. CONCLUSION

The heat transfer coefficient is determined to be 29 W/(m^2 · ºC) with semiconducting RTV coating. Further that the range of the resistance of the semiconducting RTV applied on glasses as a coating is 0.1~1 MΩ and 1~10 MΩ on insulator is proposed considering the safety of power system and the appropriate temperature.

With the heat generated by the leakage current through the semiconducting coating layer, temperature of the surfaces of the insulator increases 6~10 ºC when the applied voltage is lower. And it is effective to maintain the temperature above freezing point during cold condition.

4. REFERENCES

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Analysis of Thermal Distribution Along Insulator Strings with Semiconducting RTV

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Keywords-icing; semiconducting RTV; thermodynamic balance theory; temperature rise;

I. INTRODUCTION

Atmospheric icing affects a wide variety of structures in power network in many countries. It is well known to occur in China in winter 2008. Influencing by the low temperature wet weather, many 220kV, 500kV lines and towers are icing heavily in south of China in January 2008[1-2].

Ice accretion on overhead transmission lines and insulators has a big challenge in cold regions. To prevent similar failure, many researchers have tried to find ways to solve this problem. Two strategies are generally put into operation, "de-icing"[3-4] and "anti-icing"[5-6]. And one way to prevent ice accretion is to use a surface treatment coating to weaken the ice adhesion strength between ice and substrate. And another solution is to use a solid icephobic coating to protect the exposed surface. 2007, Liao invented a solid coating named Semiconducting RTV[7]. As the volume fraction of carbon black in the RTV increases, the resistivity decreases. When the volume fraction is suitable, the RTV silicone may start to behave as a semiconducting layer which could prevent the ice accretion on insulators when the leakage current increases to 5mA. When the semiconducting RTV is well bonded to the substrate insulator on the whole surface, a circuit loop is formed with the help of the coating layer which is in equivalent of a resistor. The value will change as soon as the voltage applied on the insulator. Hence, the heat generated by the leakage current will be not helpful during the freezing climate.

In this paper, the heating effect is studied in glass specimens with coating of semiconducting RTV in both sides using heat balance equation. And the temperature rise and distribution are monitored on the insulator with semiconducting RTV.

II. HEAT BLANCE ANALYSIS

A. Process of Temperature Rise

The heat generated by the current through the semiconducting RTV coating layer not only increase self-temperature, but also transfers to the surroundings. The process contains the heat of conduction, convection and radiation between coating layer and air. According to the First Law of Thermodynamics, the heat is conserved during the heat transfer process just as the equation (1) easily described.

$$Q = Q_r + Q_e \tag{1}$$

where Q is energy in joules generated by the conductor; Q_e is heat transferred from coating layer to the environment; Q_r is energy to raise the temperature of the layer by itself. When the current flow I through the conductor R in the time interval dt, The term Q in Eq. 1is

$$Q = I^2 \cdot R \cdot dt \tag{2}$$

And the conductor self-temperature rise of the layer can be calculated by the formula.

$$Q_r = m \cdot c \cdot d\theta \tag{3}$$

where c is the specific heat of the conductor, m is the quality of the conductor, $d\theta$ is the temperature rise. Here the progress of thermal energy converting from electric energy flowing to the environment belonged to forced convection according to the Newton's law of cooling. So the Q_e can be described as follows:

$$Q_e = K_{zh} \cdot S \cdot \tau d\tau \tag{4}$$

$$\tau = \theta - \theta_e \tag{5}$$

where K_{zh} is the constant heat transfer coefficient that depends upon physical properties of the ambient environment; S is the exposed area of heat transfer surface; τ is temperature rise of the coating layer compared to the surrounding environment; θ and θ_e are the temperature of the coating layer and ambient temperature. According to the formula (1) ~ (5), the expression of temperature rise τ_w s the following equation:

$$\begin{aligned}\tau &= \frac{I^2 \cdot R}{K_{zh} \cdot S} \cdot (1 - e^{-\frac{t}{T}}) + \tau_0 \cdot e^{-\frac{t}{T}} \\ &= \tau_w \cdot (1 - e^{-\frac{t}{T}}) + \tau_0 \cdot e^{-\frac{t}{T}}\end{aligned} \tag{6}$$

$$T = \frac{m \cdot c}{K_{zh} \cdot S} \tag{7}$$

B. State of heat balance

As soon as temperature of the conductor no longer changed, heating and cooling are equal just as the formula (8) described. P_c is the heat dissipation power. As to the coating layer, its resistance is associated with the voltage U, current I and its temperature of body. Therefore the temperature rise in the steady-state is shown as formula (9).

$$P_c = K_{zh} \cdot S \cdot \tau_w = I^2 \cdot R \tag{8}$$

$$\tau_w = \frac{I^2 \cdot R}{K_{zh} \cdot S} = \frac{U \cdot I}{K_{zh} \cdot S} \tag{9}$$

To understand heating and surface temperature of the insulator with semiconducting RTV in different environments in the semiconductor RTV, the size of the heat transfer coefficient K_{zh} need to be determined in advance. There are numerous methods for calculating the heat transfer coefficient in different heat transfer modes, different fluids, flow regimes, and under different thermohydraulic conditions. Often it can be estimated by dividing the thermal conductivity of the convection fluid by a length scale. Next step an experiment is proposed to confirm the range of K_{zh} in order to estimate the heat transfer coefficient K_{zh} when the coating layer applied on insulators.

III. HEAT TRANSFER COEFFICIENT

An experiment is designed to determine the heat transfer coefficient K_{zh}. The experiment is set up in a climate room in Laboratory of Advanced Technology of Electrical Engineering and Energy which is under the jurisdiction of The Graduate School at Shenzhen, Tsinghua University. The cold room is 1.8m×1.8m×3.0m and a minimum temperature of -20^{o} C. Schematic diagram of the main circuit of power source for the experiment is shown in Figure.1.

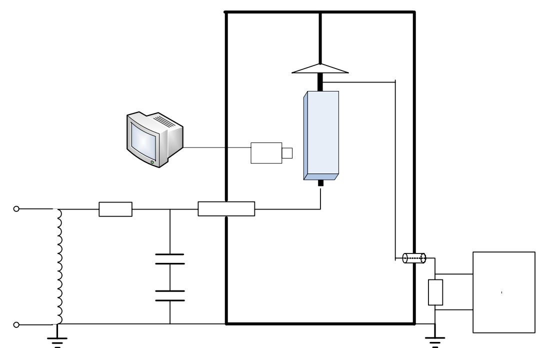

Figure.1: The 35 kV AC power source used for the test
T1-Regulator: 0.22 kV/35 kV, 50 kVA; R1-Protection Resistor: 10 kΩ; V.D-Capacitive Voltage Divider: 35 kV; S-Test Object; F- FLIR; R2-35kV bushing; R3-Resistor used for the measurement of leakage current; M- Monitoring equipment; ADLC- Acquisition device of leakage current.

The surface temperature of semiconducting RTV coated on a 0.18×0.12×0.05 glass sample. Firstly, the climate room set to the required temperature, and then the sample is put into the climate chamber to be pre-cooling. And the FLIR is opened to monitor the sample temperature. When the sample temperature is consistent with the climate when the room temperature, turn on the power and the leakage current acquisition device.

In the test, room temperature and lower temperature are both considered. When the temperature of the sample is stable, the results are obtained as shown in Figure.2.

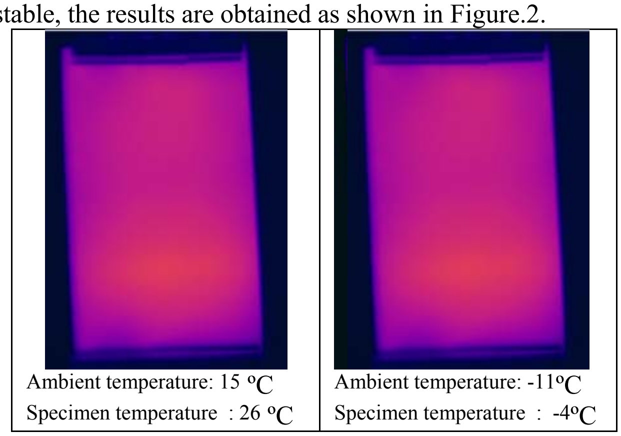

Figure.2: Uniform temperature rise in 15 ºC and -10 ºC

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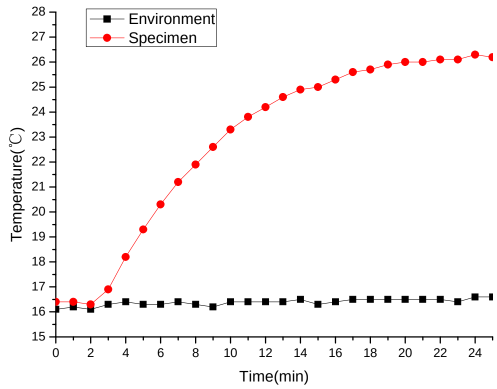


Figure.3: Temperature rise at room temperature

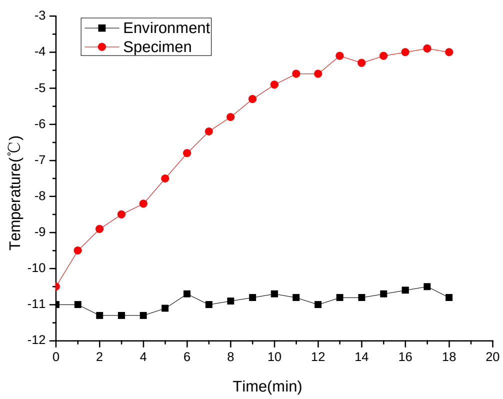


Figure.4: Temperature rise at lower temperature

From the above three figures, the temperature of the glass with semiconducting RTV will arise not only in room temperature, but in low temperature and reach a heat balance during some time just as the formula (6) states. Table.1 shows the specific data during the test.

Table 1: Temperature rise data

Temperature of ambient environment (ºC)	**Applied voltage U(kV)**	**Leakage current I(mA)**	**Temperature rise τ_w(ºC)**
15	0.52	9.52	11
-10	0.5	11.28	7

According to formula (9), K_{zh} is 20.83 W/(m^2 · ºC) at 15 ºC, and K_{zh} is 37.30 W/(m^2 · ºC). So taking the average of the two cases and K_{zh} is 29 W/(m^2 · ºC). As the semiconducting RTV is coated on single IEEE standard insulator at different resistance and variable applied voltage, the temperature rise of the surface of insulator is shown as follows. As the figure shown, the range of the resistance of the semiconducting RTV is 10^4~10^7Ω and the voltage's is 5~8kV. And the area of the insulator is 0.1480m^2.

Generally, the scale of the temperature of the freezing weather is -20~-3ºC. According to Eq.9, Figure.5 shows the calculation results of semiconducting RTV on insulator at different applied voltages and resistances and the appropriate magnitude range of resistance coated on insulator is10^5~10^6 Ω.

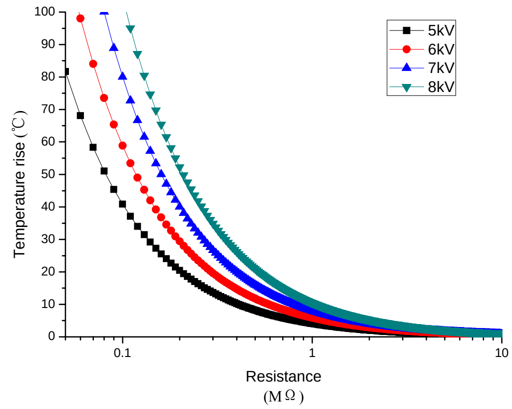
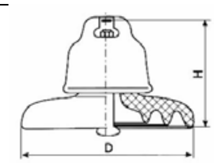


Figure 5: Calculation results of semiconducting RTV on insulator at different applied voltage and resistance.

IV. THE THERMAL DISTUIBUTION ON INSULATOR

The parameters of porcelain IEEE standard insulator are as shown in Table.2.

Table 2: Parameters of insulator used to be test

Dimensions, mm			**Insulator configuration**
Shed diameter (D)	**Unit spacing (H)**	**Leakage distance**	
254	146	305	

Test arrangement is similar to the glass with semiconducting RTV just like in Figure.1, and the only difference is replacing the sample into a single insulator. Both of two conditions, room temperature and lower temperature are both in the test.

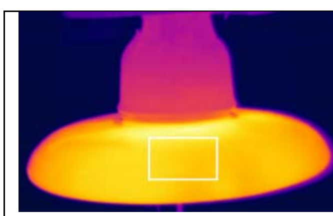
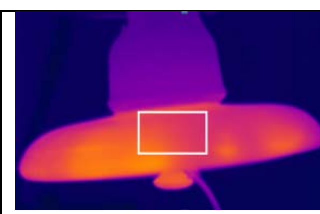
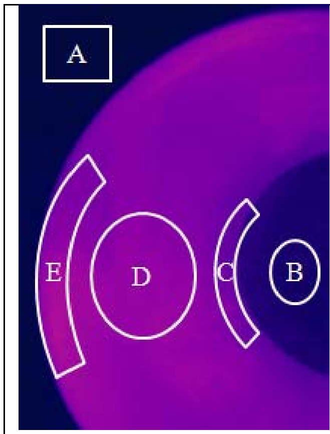
			
Voltage(kV)	2.11	**Voltage(kV)**	0.94
Leakage current(mA)	11.56	**Leakage current(mA)**	11
Ambient temperature(ºC)	18	**Ambient temperature(ºC)**	-6
Sample temperature (ºC)	24	**Sample temperature (ºC)**	19

Figure.6: Temperature rise of insulator in 18 ºC and -6 ºC

The measured resistance is 0.3MΩ in Figure.6 which shows the heating effect of semiconducting RTV on insulators at both room temperature and freezing climate. Especially, the surface temperature of the insulator during the cold condition also can increase to proper temperature, which ensure the insulator maintain a higher temperature exposed outside. As a result of that the main ice accretion are on the upper surface of the insulator. So the surface is divided into several parts to describe the temperature rise just as shown in Figure.7.



A	Air
B	Fitting of insulator
C	Interface between porcelain and fitting
D	Main surface of insulator
E	Outside shed of insulator

Figure 7: Different parts of insulator

Figure.8 shows that the temperature on the different parts of the insulator increases in some extent at 18 ºC. And the areas of maximum temperature are at area C, D and E. When the system reaches equilibrium, the surfaces with semiconducting coating reach the same temperature rise. And the fitting is also affected by the ambient area, so that the temperature will increase.

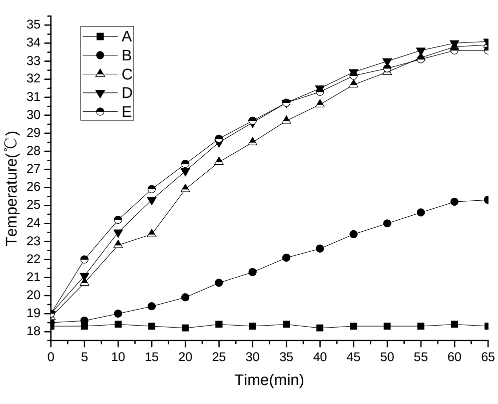


Figure 8: The thermal distribution on the insulator at 18 ºC

Figure.9 shows the temperature rise on the different parts of the insulator at -6 ºC. The applied voltage in Figure.9 is 0.94 kV and the resistance is 0.1MΩ at the balance time. In this case, a better temperature rise is already obtained, but it is very dangerous while the whole insulation distance is artificially shortened. So the magnitude of the insulator will be better at 10^6~10^7 that to ensure the safe operation of insulator and lines.

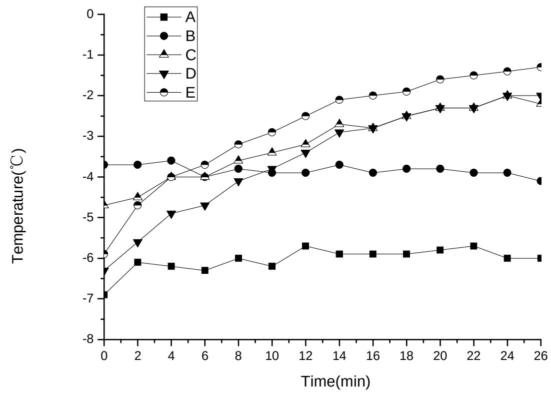


Figure 9: The temperature of the insulator at -6ºC

V. CONCLUSION

The heat transfer coefficient is determined to be 29 W/(m^2 · ºC) with semiconducting RTV coating. Further that the range of the resistance of the semiconducting RTV applied on glasses as a coating is 0.1~1 MΩ and 1~10 MΩ on insulator is proposed considering the safety of power system and the appropriate temperature.

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