Study on Electrical Properties and Field Solutions of Water Related Heating of Composite Insulators on 500kV AC Transmission Lines

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Abstract—In 2011, a composite insulator in Shenzhen suffered fracture. Through infrared thermal test along the same and neighbor lines, 517 out of 1327 insulators presented with up to or over 0.5°C thermal increase. Early researches demonstrated that humidity was a factor to have effect on heating performance. In order to understand the potential mechanism of heating and provide precaution suggestions, we conducted FEM analysis on both thermal and electrical field; mechanical load test; electrical endurance test; mechanical, microscopic configurational as well as chemical analysis upon 9 problematic insulators and compared several ways to control end side field intensity. Defective interfaces were found. Polarization of insulation material after aging and water penetration was critical to heating. In order to reduce damage, decreasing the end side filed intensity was necessary to lessen heating loss as well as decelerate aging process.

Keywords—composite insulators; water; IR results; FEM analysis

I. INTRODUCTION

Fracture of composite insulators is a serious type of accident with unknown mechanism. Through analysis of cracked insulators, researchers discovered that speedy interface quality decline could lead to fractures after water penetration.

Heating in composite insulators end sides was comprehensive. Resistance loss, polarization as well as partial discharge all could lead to abnormal heating[1-2]. During operation, we conducted IR thermal test on several samples before fracture and discovered significant thermal increase around fracture site. Due to limitation of fracture and small sample size, the relationship between heating and fracture was still ambiguous[3].

In 2011, one 500 kV composite insulator in southern china suffered fracture with different characteristics. IR thermal test alone the same and the neighbor line indicated different level of heating around HV site of 517 insulators. In addition, anatomical investigation found 0.4 mm deep erosion track on several core surfaces. In this article, we initialed a study through sampling inspection and investigated samples' chemical and electrical properties in order to understand the relation between heating and fracture.

II. HEAT DISSIPATION FACTOR

When a defect was generated within composite insulators, the cooling process proceeded via heat dissipation in the sheath and sheath-air convection[4]. If axis z represent central core axis, r1 represent core diameter, r2-r1 represent sheath thickness, so the heat dissipation and convection fit in the equation1 and equation2 respectively,

\[ C_v \frac{\partial u(t, r, \theta, z)}{\partial t} = \kappa \nabla^2 u(t, r, \theta, z) \]  

(1)

\[ \kappa \left( u_{r=r_1} - T_0 \right) = \kappa \frac{\partial u}{\partial r}_{r=r_2} \]  

(2)

where \( u(t, r, \theta, z) \) represent thermal field, represent time and \((r, \theta, z)\) represent site. \( C_v \) is heat capacity per unit volume, \( \kappa \) means heat dissipation parameter, \( T_0 \) is outside temperature and \( \kappa \) is convection parameter.

If we omit the effect of radiation and consider defect and insulator as infinite, in the mean time maximize \( T_0 \) to neglect the imbalance of \( \theta \), we generate:

\[ T_1 = -\beta \frac{\ln \frac{r_2}{r_1}}{r_2 \left( \ln \frac{r_2}{r_1} - \beta \right) + \ln \frac{r_2 \beta}{r_1 \beta}} T_2 + \frac{\ln \frac{r_2}{r_1}}{r_2 \left( \ln \frac{r_2}{r_1} - \beta \right) + \ln \frac{r_2 \beta}{r_1 \beta}} T_3 \]  

(3)

where \( T_1 \) represent the max of outside temperature, \( T_2 \) represent defect temperature, \( T_3 \) represent environment temperature, \( \beta \) represent the ratio of heat dissipation and convection. As a result, the defect temperature was linearly related with outside temperature and closely related with material, size as well as the environment.

A thermocouple was embedded into the interface of core and sheath. Using IR detector to keep record of the heating on the outside. The size of thermocouple was 30*5*0.5mm.
thickness of sheath was 6mm; the core diameter was 24mm. (see Fig. 1)

In Fig. 1, the max of outside temperature was linearly related with internal defect temperature. In the humidity and air speed effect analysis, we discovered that the effect of 1~3m/s wind speed toward IR test is negligible, however, when the humidity level was high, the IR test seemed to be lower than low humidity level (see Fig. 2). IR tests in the next section were carried out indoor with limited wind effect.

III. IR TEST AND MECHANICAL PROPERTIES

All the insulators were manufactured from the same supplier with same grading ring. They were installed into 1-String. We randomly selected 9 samples (5#, 16#, 24#, 33#, 51#, 61#, 70#, 99#, 101#) out for mechanical and IR test.

We adopted horizontal tensile machine to provide specified mechanical load test and failure load test on these 9 samples. The exact procedures were as follows:

a. Stably and swiftly enhance fixed mechanical load to 0.75SML and maintain for 30s;

b. Enhance fixed mechanical load by 1kN/s and maintain for 1min;

c. Enhance fixed mechanical load by 1 kN/s until break off.

As a result, all the insulators kept unbreakable for over 1min in specified mechanical load test. When the intensity of failure load reached 1.4SML~1.6SML, all the cores could be extracted from the metal fitting on the end site, which indicated that the mechanical properties of heated insulators remained acceptable.

Before the DC and AC tests, superficial pollutants were washed off. During AC test, the exerted voltage was 318kV, 1.1 fold of voltage in function. Both high (70% ± 5%) and low (35 ± 5%) level of humidity were considered. During DC test, the exerted voltage was 449kV, in equivalent with the peak of AC voltage. Only high level of humidity (70% ± 5%) was involved.
During tests, none of the insulators developed corona discharge when observed by UV analyzer. The AC test indicated that under high level of humidity, insulators all heated on the HV site; on the contrary, only one (99#) heated on the HV site with low humidity level(see Fig.3). When switched to DC test, the results resembled that of AC-low humidity, meaning only 99# insulator heated(see Fig.4).

Combined with the former tests, we suggest that for the majority, heating was developed due to polarization loss and was closely related with water. In some rare case, take 99# insulator for example, their heating mechanism was more comprehensive.

IV. DISSECTION RESULTS AND CHEMICAL ANALYSIS

Through anatomical analysis, we detected a 0.4mm deep erosion track on the medial surface of core where heated in the test(see Fig.5). This phenomenon was not observed in any other insulators.

We also conducted element and FTIR analysis toward medial sheath and core material on the HV site of 51# and 99# insulators, along with a brand new sample provided by the supplier.

Compared with 51# insulator, the sheath material of 99# insulator presented with significantly less carbon and more oxygen. The magnitude of carbon decrease was similar to the increase of oxygen[5-6]. The core of 99# insulator was also detected with more nitrogen(see Table I). In this case, we suggested that AC discharge happened in the inner layer at heated site of 99# insulator. Corona discharge should be the main reason for the heating of 99# insulator.

![Erosion Track](image)

Fig. 5. The erosion track on the HV site of the core(parallel to fibers )

V. ELECTRICAL FIELD CONTROL SOLUTION

For insulators without apparent internal defects like 51#, risk of fracture was lower due to acceptable mechanical and electrical properties. In order to keep them from constant heating related dysfunction, side electrical field intensity control was necessary. During model construction, we neglected the effect of gridded tower structure on electrical field simulation results. We also neglected the effect of insulators and wires on field intensity for simplification. Considering the reality and results from Ansoft FEM simulation, we proposed two possible plans: I. Enhance blockage depth from 50mm to 90mm, then the side field intensity would drop 17.4% and the voltage within 20cm range would decrease 18.5% ; II. Add two more glass insulators(Type:U210) at HV side to make side field intensity drop 10.8%, voltage within 20cm decrease 33.8%. Due to thunder effect, we finally selected plan b over plan I.

To verify the effectiveness of controlling side electrical field intensity, we conducted voltage loading test on samples with glass insulators and samples with enhanced shielding depth. We randomly selected 6 heated insulators and loaded with 318kV voltage. Three different methods were adopted: a. direct voltage loading; b. change blockage depth; c. add two more U210 glass insulators(see Fig.6). IR thermometry was engaged. The voltage loading endurance was 2h with humidity over 70%.

![Voltage Loading](image)

Fig. 6. 2 extra glass insulators(left) and a less shielding depth(right)

As a result, we can found that when glass insulators were added, side heating was significantly controlled(see Table II). Due to the potential relationship between heating and side integral voltage, the simulation results suggested glass
insulators could significantly decrease side integral voltage and therefore more effective for heating control.

TABLE II. Thermal rise under high level of humidity after addition of glass insulators.

<table>
<thead>
<tr>
<th>Temperature rise</th>
<th>1#</th>
<th>28#</th>
<th>37#</th>
<th>65#</th>
<th>82#</th>
<th>105#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference group</td>
<td>4.4</td>
<td>3.2</td>
<td>2.7</td>
<td>2.7</td>
<td>4.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Change Shielding</td>
<td>2.4</td>
<td>1.8</td>
<td>1.6</td>
<td>1.5</td>
<td>2.3</td>
<td>2.6</td>
</tr>
<tr>
<td>depth 2 more glass insulators</td>
<td>0.9</td>
<td>0.7</td>
<td>0.5</td>
<td>0.6</td>
<td>0.8</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Besides, thunder is another threat. So glass insulators were more preferable. Later, mechanics from Shenzhen power supply bureau applied this modification into the neighbor lines of the accident and has already start functioning.

VI. RESULTS AND DISCUSSION

In this research, we studied a composite insulator heating accident in southern China. Through multiple analysis, we suggest:

a. For most insulators without internal defect, polarization loss of elements and water were main reason for HV side heating. Due to acceptable mechanical properties, replacement was unnecessary within short time.

b. For insulators with internal defect, the corona discharge was key to heating and required immediate replacement.

c. Field test could be carried out under low wind speed and low humidity level. To prevent side thermal rise, two glass insulators may be helpful.

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REFERENCES


