Partition Study on Leakage Current Characteristics of Artificial Pollution Experiment on Catenary Insulator

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Abstract. In this paper, the catenary insulator FQX-25 is selected to do artificial pollution experiments. Firstly, study on the partition of experimental data by using the variation characteristics of the leakage current then re-determine the partition threshold of the safe zone, forecast zone and danger zone which are 10 mA and 30 mA. Secondly, the RMS and the pulse time domain entropy are obtained and the relationship between them and pollution level is fitted by Matlab. The research shows that the RMS of the leakage current and the pulse time domain entropy have very good exponential fitting relation with the equivalent salt deposit density (ESDD). The results of this study can provide a new way to evaluate the pollution level of insulators.

Introduction

The maintenance operation of the catenary has always been the important links to ensure the safety of railway transportation. The insulator is an important part of the catenary which plays an important role in mechanical support and electrical insulation. It is affected by a variety of over voltage in the running time (Wan-ju YU, 2003). In fact, the catenary insulator set up in the polluted areas which in rainy weather or high humidity environment, pollution flashover may also occur even at normal operating voltage (Zhi-tao Zhang, Xiao-bing Jing, Tang-long Chen, 2014). Therefore, it is of great engineering significance to analyze the leakage current characteristics of the catenary insulator.

Cai-xin Sun, Wen-xia Sima and Li-Chun Shu (2002) point out that the biggest influence factors of insulator pollution flashover include pollution level, insulation level, running voltage and environmental factors and so on. The leakage current can comprehensively characterize the changes of voltage, climate and pollution, and it is a dynamic parameter to characterize the state of pollution level (Le-guan Gu, Cai-xin Sun, 1990). In this paper, the whole process leakage current waveforms of the catenary insulator flashover process are analyzed. According to a large number of experiment data and field data to re-determine the partition threshold of each zone. The RMS, the number of pulse and the time domain entropy of each zone are obtained, it is concluded that the RMS and the pulse time domain entropy of the danger zone can be more accurate to characterize the surface pollution of insulator when comparing the data of each section. These data are used to characterize the pollution level of insulator, which provides some reference for the railway sector to make the plan of cleaning and replacement for insulators.

Experimental Equipment and Methods

Experimental Devices

Artificial pollution experiments was carried out in the artificial climate chamber of the high voltage laboratory in LanZhou JiaoTong University, The size of the chamber is 1.2 m × 1.2 m × 1.8 m, and the wiring principle diagram is shown in Figure 1. All the test equipment meet the requirement of the national standard GB/T 4585-2004 for AC pollution test power supply (National Standardization Technical Committee, 2004). The test power supply and leakage current collection device are shown in Figure 2. The test insulator is FQX-25 for railway. The solid coating method was used to configure the 4 different levels of pollutant solution quantitatively and evenly coated on the surface of the insulator to be tested (Electrical Engineering of the Ministry of Railways, 1997), The
insulator leakage current collection board developed by Art Company in Beijing is used to collect the test data in real time, it is displayed on the LabVIEW user interface and saved.

**Experimental Method**

The mixed solution of sodium chloride and diatomite is evenly brushed on the surface of insulator before the experiment started and then standing suspension for 24 h to dry naturally. The solution ratio is shown in Table 1. Move the insulator to the artificial climate chamber to simulate the field operating conditions, and then adjust the mist generator to make the relative humidity above 95% and keep stable. If there are some small water droplets on the surface of the insulator, it means that the pollution layer is damp saturated. At this time, immediately apply 27.5 kV voltage to the insulator to test, the leakage current collecting device will automatically display and save the data.

![Figure 1. Schematics of the artificial pollution test.](image1)

![Figure 2. Test power supply and collection device.](image2)

![Table 1. Test pollution matched table.](image3)

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>ESDD (mg/cm²)</th>
<th>NSDD (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>0.04</td>
<td>0.4</td>
</tr>
<tr>
<td>No.2</td>
<td>0.1</td>
<td>1.0</td>
</tr>
<tr>
<td>No.3</td>
<td>0.2</td>
<td>1.5</td>
</tr>
<tr>
<td>No.4</td>
<td>0.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The experiment was carried out immediately after saturated wetting of the pollution layer, the aim was to avoid water droplets from gathering along the edge of the insulator umbrella skirt and drip, which would affect the accuracy of salt density. This method can restore the actual operation condition of the insulator, and the experimental data is more reliable.

**Experiment Waveform Analysis**

The leakage current waveform of FQX-25 type insulator in different pollution level is shown in Figure 3.

![Figure 3. The original waveform of leakage current under different pollution levels.](image4)

**Leakage Current Waveform Analysis**

Jing-yan Li (2010) has claimed that the whole process of pollution flashover can be divided into 3 main zones, they were named safe zone, forecast zone and danger zone and the partition threshold
of each zone was 50 mA and 150 mA. But we find that the experimental data from Xiao-bing Jing (2015) and Yi-xing Li (2015) which special study on the catenary insulator is somewhat different from Jing-yan Li. Even when the insulator flashover occurs, the amplitude of leakage current is much lower than 150 mA, the test data we collected from the high voltage laboratory also confirms this point.

Jing-yan Li (2010) has also claimed that the waveform characteristics of the leakage current can be deduced, and the discharge principle of insulators in different voltage and pollution levels can be derived by using this characteristics. Therefore, we use this characteristics to re-determine the partition threshold of the 3 zones, which is important to predict flashover voltage and pollution level.

**Waveform Characteristics Analysis of Each Zone**

In this experiment, the whole process leakage current waveform of the pollution flashover is analyzed and compared, and the leakage current waveform is shown in Figure 4.

In Figure 4, the waveform of safe zone 1-3 reflect the development and change of the leakage current. In safe zone 1, the waveform is a periodic sine wave, and basically has no flashover. In safe zone 2, the waveform is still a periodic sine wave, but the amplitude is slightly increased, with a slight discharge, accompanied by a weak discharge sound. In safe zone 3, the leakage current amplitude is further increased, the waveform gradually evolved into a nearly triangular waveform, with punctate discharge and a brief discharge sound at the same time.

In Figure 4, the waveform of forecast zone 1-3 reflect the development and change of the leakage current, in the forecast zone 1, the distortion of the waveform is more obvious than the safe zone, there is a brief zero-break phenomenon accompanied by spikes, and the periodicity of the waveform is not obvious. in the forecast zone 2, the waveform is seriously distorted and the amplitude is changed violently, the discharge is enlarged to form local arc and accompanied by discharge sound. In the danger zone 3, the waveform distortion is more serious, the partial discharge is more intense, and the amplitude of the leakage current is obviously increased.

![Figure 4. Waveform of each zone when $\rho_{ESDD} = 0.2 \text{mg/cm}^2$.](image-url)
After entering the danger zone, the leakage current amplitude increases, the waveform re-presents a continuous non-uniform sine wave, but the phenomenon of zero-break longer, the corresponding phenomenon is a bright long arc and accompanied by a strong discharge sound. After this, the arc has increased sharply until the main arc crosses the insulator and then flashover, at this point the amplitude of the leakage current increases sharply, and the transformer is tripped by the protection circuit.

It is found from the above analysis that the leakage current waveform of the catenary insulator having 3 zones also, Large number of repeated experiments show that 10 mA and 30 mA can be used as the partition threshold of the 3 zones, which is reasonable for the catenary insulator. The waveforms from Xiao-bing Jing (2015) and Yi-xing Li (2015) has also fully confirm this conclusion.

Spectrum Analysis of Leakage Current

RMS of Leakage Current

The RMS of leakage current is recommended by the 33rd Committee of the Conference International des Grands Reseaux Electriques (CIGRE). Its magnitude can reflect the changes of the leakage current, so it is widely used in the research on leakage current characteristics, its definition is

\[
I_e = \sqrt{\frac{1}{N} \sum_{i=1}^{N} I_i^2}
\]  

In the formula (1), ‘\(N\)’ is the number of sampling points and ‘\(I_i\)’ is the leakage current amplitude at the time of ‘\(i\)’.

If the traditional method is used to calculate the RMS of the whole process leakage current, the unique features of each zone will be weakened by other zones. In order to explore the relationship between leakage current and the ESDD more accurately, this paper studies the relationship between the RMS of the leakage current and the ESDD on different zones. The RMS of the leakage current in the safe zone, the forecast zone and the danger zone in Figure 3 are calculated respectively using the formula (1). The results are shown in Table 2.

The RMS in Table 2 and the corresponding pollution level are plotted and the connection map is shown in Figure 5. It can be seen from Figure 5 that the RMS of each zone increases with the increase of ESDD in saturated humidity condition, but the RMS of the danger zone is more obvious than that of the safe zone and the forecast zone. This feature can be derived from the previous analysis.

<table>
<thead>
<tr>
<th>Pollution Level (mg/cm²)</th>
<th>0.04</th>
<th>0.1</th>
<th>0.2</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe Zone</td>
<td>0.63</td>
<td>0.88</td>
<td>1.22</td>
<td>1.71</td>
</tr>
<tr>
<td>Forecast Zone</td>
<td>2.07</td>
<td>2.8</td>
<td>3.03</td>
<td>4.74</td>
</tr>
<tr>
<td>Danger Zone</td>
<td>8.34</td>
<td>8.92</td>
<td>11.05</td>
<td>22.54</td>
</tr>
</tbody>
</table>

Figure 5. RMS and pollution levels relationship

Figure 6. RMS of danger zone and pollution levels fitting curve.
According to Chun-hua Fang, Jian-guo Wang, Ping-mei Cao, Kang Wang (2012), the exponential relationship of RMS of leakage current \( I_e \), relative humidity \( RH \) and \( \rho_{ESDD} \) can be obtained like this

\[
I_e = a_i \times \rho_{ESDD}^b + c_i \tag{2}
\]

The RMS of the leakage current in danger zone and the ESDD were fitted by Matlab, the curve is shown in Figure 6. The fitting parameters are as follows. \( a_i = 124.8 \), \( b_i = 2.371 \), \( c_i = 8.324 \). The curve fitting level was \( R^2 = 0.9998 \), the standard deviation was \( \sigma = 0.0816 \). It can be seen that both of them have very good exponential fitting relation, which can meet the engineering needs. Therefore, the RMS of the catenary insulator leakage current can effectively characterize the pollution level of the insulator.

**Leakage Current Pulse Counting**

Pulse counting method is also recommended by the 33rd Committee of the CIGRE. In this paper, the leakage current pulse amplitude is divided and statistics hierarchically, in order to characterize the insulator pollution level is called pulse counting method.

The sampling frequency in the experiment is 8 kHz, and the leakage current waveform of 10 second is taken, so there are 80000 data points. The amplitude of the leakage current is divided into 6 grades, which are 0-1 mA, 1-5 mA, 5-10 mA, 10-20 mA, 20-30 mA and more than 30 mA. The distribution of leakage current amplitude is shown in table 3.

As can be seen from the table 3, the number of pulses per grades is reduced with the increase of the threshold, which shows that the main component is a low amplitude pulse. And with the increase of pollution degree, the distribution of the leakage current amplitude is more dispersed. In order to find out the dispersion law, the formula of distribution density and time domain entropy are introduced.

<table>
<thead>
<tr>
<th>ESDD (mg/cm²)</th>
<th>0.04</th>
<th>0.1</th>
<th>0.2</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 mA</td>
<td>57694</td>
<td>48495</td>
<td>28334</td>
<td>16298</td>
</tr>
<tr>
<td>1-5 mA</td>
<td>21771</td>
<td>27876</td>
<td>29990</td>
<td>28874</td>
</tr>
<tr>
<td>5-10 mA</td>
<td>525</td>
<td>2222</td>
<td>10042</td>
<td>6328</td>
</tr>
<tr>
<td>10-20 mA</td>
<td>0</td>
<td>1333</td>
<td>8421</td>
<td>11583</td>
</tr>
<tr>
<td>20-30 mA</td>
<td>0</td>
<td>63</td>
<td>2359</td>
<td>9048</td>
</tr>
<tr>
<td>&gt;30 mA</td>
<td>0</td>
<td>0</td>
<td>853</td>
<td>7867</td>
</tr>
</tbody>
</table>

\[ r_i = \frac{n_i}{N}, \quad i = 1, 2, ..., l \tag{3} \]

In the formula (3), ‘\( n_i \)' is the number of data points within the range of ‘\( i \)' , ‘\( N \)' is the total number of data points, ‘\( l \)' is the number of grades.

\[ R = -\sum_{i=1}^{l} r_i \log r_i \tag{4} \]

Using formula (3) and (4) to calculate the time domain entropy of leakage current under different contamination degree, the results are shown in table 4.

<table>
<thead>
<tr>
<th>Pollution Level (mg/cm²)</th>
<th>Pulse Time Domain Entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0.2705</td>
</tr>
<tr>
<td>0.1</td>
<td>0.4066</td>
</tr>
<tr>
<td>0.2</td>
<td>0.6016</td>
</tr>
<tr>
<td>0.4</td>
<td>0.7153</td>
</tr>
</tbody>
</table>
The data in Table 4 are plotted and the formula (2) is used to fit the data, the fitting curve is shown in figure 7. The fitting parameters are as follows. \( a_1 = 2.264 \), \( b_1 = 0.1111 \), \( c_1 = -1.321 \). The curve fitting level was \( R^2 = 0.9583 \), the standard deviation was \( \sigma = 0.04049 \). It can be seen that both of them have very good exponential fitting relation, which can meet the engineering needs. So, the pulse time domain entropy of the leakage current can be used to evaluate the characteristics of insulator pollution.

Conclusions

The leakage current of the catenary insulator is studied by using the mature zoning theory. A large number of test data were analyzed and compared with the relevant reference data to re-determine the partition threshold for the catenary insulator leakage current, they were 10 mA and 30 mA respectively.

Fitting the experimental data, It is concluded that the relationship between the RMS \( (I_e) \) of the danger zone leakage current of the catenary insulator and \( \rho_{ESDD} \) is

\[
I_e = 124.8 \cdot \rho_{ESDD}^{2.371} + 8.324. \tag{5}
\]

The relationship between the pulse time domain entropy of the leakage current and \( \rho_{ESDD} \) is

\[
R = 2.264 \cdot \rho_{ESDD}^{0.1111} - 1.321. \tag{6}
\]

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References


