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Leakage Current Analysis of Bushing with Water-cut Sheds in Heavy Rain Test

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Abstract: In this article, heavy rain tests under two rainfall intensities are introduced. Three kinds of bushings with different water-cut-sheds were used in these tests. Then leakage currents monitored during tests are analysed and contrasted to obtain characteristics and tendency. The results show that maximum value of leakage current is affected by voltage applied, profile of water-cut sheds, and the rainfall intensity. Higher AC voltage applied on bushing leads to higher peak of leakage current. More and larger water-cut sheds makes bushing able to withstand higher leakage current. Heavier rain may cause leakage current rise totally. These results may be helpful in online monitoring of insulation.

1. Introduction

The property of pollution and wet is always taken into account on the external insulation selection of the outdoor substation equipment. The main method of the external insulation design is on the basis of the pollution flashover property. Previous research [1] [2] showed that: when in heavy rain condition, there are rain curtains formed by water with high conductivity beside the surface. Flashover occurs along the rain curtains, not on the surface. So mechanisms and characteristics of pollution flashover and heavy rain flashover are different. The outdoor equipment whose external insulation is selected through the method above may flashover in heavy rain condition. And research on the method of protecting equipment from heavy rain flashover is needed.

Water-cut shed is generally accepted as an effective protective method in heavy rain condition. It can cut the rain curtains off, decreasing the probability of heavy rain flashover. Water-cut sheds are usually made from silicone rubber, and bonded with the bushing sheds.[2] But there are some problems on bonding strength and mechanical property. Porcelain bushings manufactured with several water-cut sheds on it may avoid these problems.

Leakage current analysis is an auxiliary method to monitor the status of the insulated surface while high voltage is applied on it. Researchers in STRI carried out rain test of hydrophilic porcelain post insulators, and calculated the resistive component and capacitive component of the total leakage current. They observed the change of currents under different rain density. [3] Indonesian researchers presented the characteristics of leakage current at different shed of epoxy resin insulator under rain contaminants, and compared characteristics of leakage current under rain and dry test. [4] But they only gave single values, ignoring the tendency of leakage current during the period from voltage applying to flashover or withstand.

In recent years, there were several heavy rain flashover accidents on bushings occurred in EHV substations in China. To improve the ability of withstanding heavy rain flashover, effective and economical protection measures should be raised according to EHV bushing rain tests.

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In this article, heavy rain flashover tests were carried out on porcelain bushings with different water-cut sheds. Leakage currents monitored during the flashover tests are contrasted to find the change rule of it.

2. Specimens

Three types of 500 kV porcelain bushing with different water-cut shed configurations were used in this test. Their insulation height are all 4.7 m. One of them is common bushing with no water-cut shed, the others are with four and eight water-cut sheds, respectively. Table 1 gives parameters of those tested porcelain bushings, and figure 1 shows the pictures of three porcelain bushings.

Table 1. Parameters of tested specimens

Number	Leakage Distance (mm)	Number of Water-cut Sheds	Spacing of Water-cut Sheds (mm)	Overhang of Water-cut Sheds (mm)
1	18775	0	-	-
2	18775	4	1165	50
3	19200	8	580	95

Figure 1. Profiles of tested specimens.

Figure 2. Set-up of artificial rain test.

3. Test facilities and procedures

3.1. Test facilities

Artificial heavy rain flashover tests were carried out at the Pollution and Environment Laboratory in State Grid UHV DC Test Base, which is located in Changping, Beijing. Tested bushings were installed vertically in the artificial environmental chamber which has a test space of 20 m in diameter and 25 m in height. It is capable for environmental tests such as icing, raining and fogging. Figure 2 shows the set-up of artificial rain test in the chamber.

The main circuit of AC power supply of the artificial heavy rain flashover test is shown in figure 3. It meets the requirement of IEC 60507 [5]. T1 is 4800 kVA regulator. T2 is the AC test transformer of 800 kV, 4800 kVA. R1 is the protecting resistance, and V.D is the AC voltage divider. T.O is the specimen and R2 measures the leakage current during the test. The leakage current measurement system is designed by Graduate School at Shenzhen, Tsinghua University. The sampling rate of this system is 5 kHz. figure 4 shows the signal processing module and leakage current monitoring module.

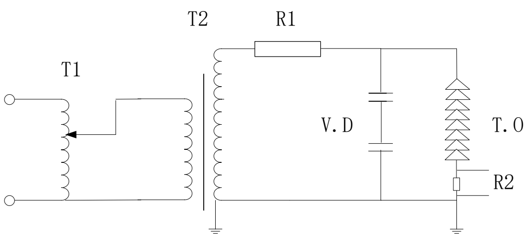

Figure 3. Profiles of tested specimens.

Figure 4. Set-up of artificial rain test.

The rain simulator is consist of water container and shower device. The shower device is installed on a platform which could move up and down freely. There is a 4×12 nozzle matrix on the shower device. Each nozzle can change the shooting direction of the water. Through adjusting nozzles, we make sure the artificial rain dropping on the bushing slantingly. The angle between rain direction and horizon is about 45º, which means horizontal component and vertical component of the rain are almost the same. The 45º raining is regarded as the worst raining condition because rain may wet the upper and bottom of sheds evenly.

The measurement of rainfall intensity used special device. It has a long stick. There are two metal container on the top of the stick. One has a horizontal opening, collecting the vertical component of the rain. The other has a vertical opening, collecting the horizontal component of the rain. Rainfall intensity was calculated according to the water in two containers after collecting rain for 1 min. Rainfall intensity of 5 mm/min and 10 mm/min were required in this test for continuous rain curtains with high conductivity.

3.2. Test procedures

The pollution layer was sprayed on the surface of specimen according to IEC 60507. The insoluble contamination was kaolin. To stop the pollution layer being washed away too quickly, gelatin was added into the suspension. The value ratio between sodium chloride and kaolin is 1:6, and the value ratio between gelatin and kaolin is 1:10. After spraying, wash test should be done according to IEC 60815 [6] to make sure the ESDD is 0.1 mg/cm^2 within the error range of ±10%.

After dried completely in shady place, the tested bushings were installed in chamber. Firstly, a preset voltage was applied on the specimen, and then the rain started. Rain duration was at least 5 min if no flashover occurred.

4. Characteristics of leakage current

4.1. Leakage currents of one bushing under different voltages

Firstly, the leakage current under different voltages applied on bushing with four water-cut sheds are compared. Because leakage waveforms change on the 50 Hz frequency, we use upper envelope instead to find out how amplitude changes. Figure 5 shows the upper envelopes of each leakage current wave under U_1 、 U_2 and U_3 after 5mm/min rain starting. The order of three voltage is $U_1 < U_2 < U_3$.

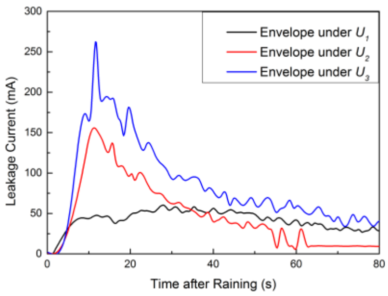

Figure 5. Leakage current envelope under Different Voltage.

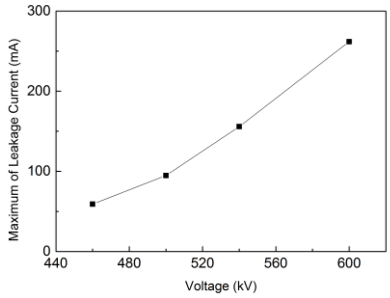

Figure 6. Maximum of leakage current under different voltage.

As is displayed in figure 5, when U_1 is applied and rain starts, the leakage current increases to about 50 mA, then waves around. When U_2 is applied and rain starts, the leakage current firstly increases and reaches the maximum of 150 mA, then decreases to a very low value. When U_3 is applied and rain starts, the leakage current increases to more than 250mA and decreases. The curves of leakage current aren't smooth, and little peaks on them indicate that there are partial arcs appearing and disappearing on the surface. Those processes described above are all happened in 80 s after artificial rain showering on the surface of bushing. We can see that the maximum of current has positive correlation with the applied voltage from direct comparison in figure 6. Trend of curves are the same if voltage is high enough and flashover doesn't occur.

4.2. Leakage currents of three bushings under identical rainfall intensity

There is significant diversity between 50% flashover voltage of three bushings. It's impossible to contrast currents of bushings under identical voltage. Therefore, leakage currents under the highest withstand voltage of each bushing are contrasted. Figure 7, figure 8 and figure 9 are the upper envelopes of three bushings' leakage currents. Tests were carried out at 5 mm/min rainfall intensity.

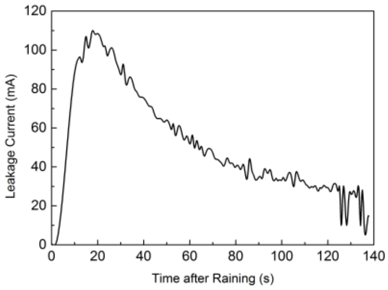

Figure 7. Leakage current envelope of No.1 bushing.

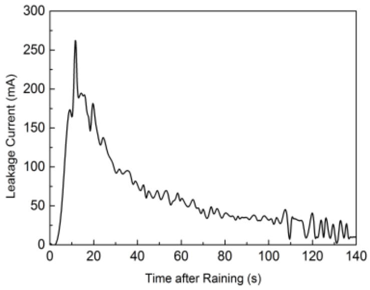

Figure 8. Leakage current envelope of No.2 bushing.

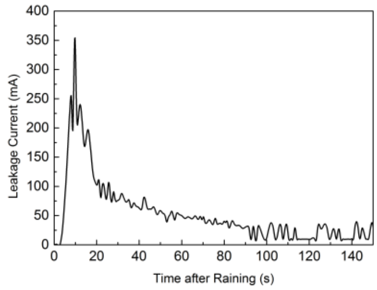

Figure 9. Leakage current envelope of No.3 bushing.

As shown in figure 7, figure 8 and figure 9, the trends of curves are all firstly rising quickly to the maximum, then decreasing to less than 50 mA, finally fluctuating in a limited range. It matches three stages of bushing surface. Firstly, rain washes away the contamination on the surface. Resolving salt in contamination, high conductivity rain curtain makes leakage current rise rapidly. Possibility of flashover is highest in this stage. Then if flashover doesn't occur, leakage current decreases as salt is resolved less in the rain curtain. Finally leakage current fluctuates because of the appearance and disappearance of partial arcs.

The maximum value of leakage current is about 110 mA on the surface of bushing with no water-cut shed, about 260 mA on the surface of bushing with four water-cut sheds and about 350mA on the surface of bushing with eight water-cut sheds. So water-sheds protect bushing from flashover when higher leakage current flows on the surface.

Harmonics of leakage currents on three bushings are also analysed. Ten cycles of waveform around the maximum value are chosen. The fundamental component of leakage current is calculated through FFT (fast Fourier transform), as well as 3rd, 5th, and 7th harmonics. Since the maximum values of three bushings' leakage currents are different, direct compare of harmonics is meaningless. Instead, relative values of harmonics are shown in figure 10, supposing relative value of fundamental component is 100%. Obviously, 3rd harmonic is the main harmonic in leakage current. The relative value of 3rd harmonic rises if bushing has more and lager water-cut sheds. 5th and 7th harmonics can be ignored because their values are less than 5% of fundamental component.

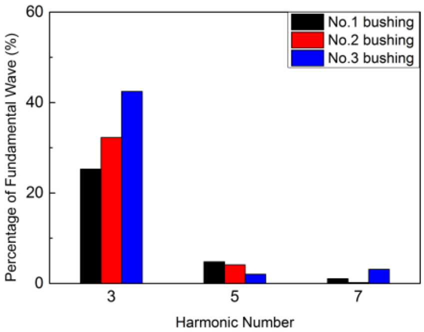

Figure 10. Relative values of harmonics.

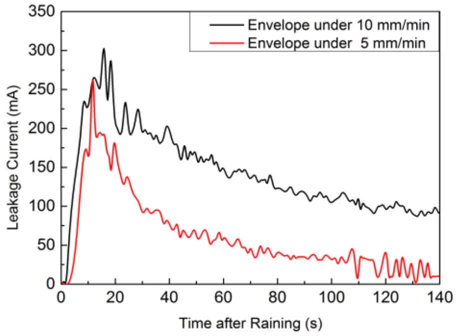

Figure 11. Leakage current envelope of No.2 bushing under different rainfall.

4.3. Leakage currents of one bushing under different rainfall intensities

Bushing with four water-cut sheds (No.2) was tested under 5mm/min and 10mm/min rainfall intensity. The leakage current under these two conditions are compared in figure 11. As rainfall intensity

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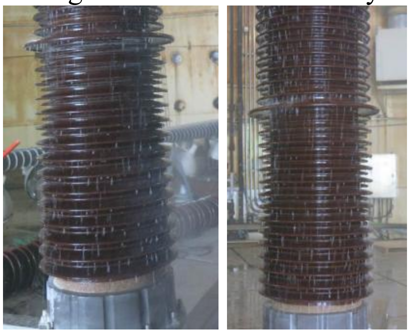
increases from 5 mm/min to 10 mm/min, the maximum value of leakage current increases from 260 mA to 310 mA approximately. After raining for enough long time, the leakage current value maintains during 50 mA and 100 mA under 10 mm/min rainfall intensity. Contrastingly, the leakage current decreases lower than 50 mA under 5 mm/min.

The diversity between leakage currents under different rainfall intensity has relationship to the rain curtains. Figure 12 shows the distribution of curtains on the bottom of bushing under 5 mm/min (a) and 10 mm/min (b) rainfall intensity. Significantly, rain curtains under 5 mm/min is less than that under 10 mm/min. Less rain curtains means leakage current flowing longer distance on the contamination layer. Since the layer's resistance is larger than rain curtain, leakage current's maximum value and stable value are larger as the rainfall intensity increases.



(a) (b)

Figure 12. Distribution of rain curtains on bottom of No.2 bushing.

5. Conclusion

From the analysis above, we can conclude that leakage current in heavy rain test is affected by voltage applied, profile of water-cut sheds, and the rainfall intensity. Following is the conclusions in detail.

a) The maximum value of leakage current has positive correlation with the applied withstand voltage.

b) The maximum of leakage current is higher with more and larger water-cut sheds under the same rainfall intensity and withstand voltage.

c) The maximum and stable values of leakage current on the same bushing are higher when the rain is heavier.

Through analysing the of rain test under the highest withstand voltage, the typical tendency and characteristics of leakage current are obtained. Those are helpful in online monitoring of insulation in substation. And the status of equipment insulation can be diagnosed easily through leakage current monitoring.

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