A Study of the Contamination Flashover at Actual High Altitude

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Abstract: The AC contamination experiments on physical model are carried out in the fog chamber of Tibet High Altitude Test Base, State Grid Corporation of China, which is the first test base ever built at 4300m above sea level. The propagation of local arc along wet contamination surface has been studied with high speed camera, which is synchronous with current and voltage measurement. It is demonstrated that the arc length grows with the increase of current. However, the arc propagation characteristic is not the same from sea level to the high altitude. The fewer current and the lower voltage are expected to maintain a specific length of arc at high altitude. The obvious differences of current and voltage between experimental results and calculation show that the low pressure influences not only the VI characteristic of arc but also the propagation condition that should be further investigated

1 INTRODUCTION

Accidents caused by contamination flashover become serious threats to the stable operation of power system, since they always happen simultaneous in large areas and lead to blackout for long time. The decrease of pollution flashover voltage in high altitude makes the design of outdoor insulation the key technical problem in the construction of HV&EHV power transmission lines as the air electric strength and arc VI characteristic would greatly decline in low pressure.

To investigate the contamination flashover characteristic of insulators under low pressure, the State Grid Corporation of China has built a test base in Tibet with the altitude of 4300m, which is the first electric power test base in the world with the altitude of more than 4000m. Many experiments such as artificial pollution tests, long air gap flashover under operating impulse and lightning impulse, electric environmental tests can all be conducted in this test base to solve the problems encountered in the HVDC & HVAC transmission projects in high altitude.

A great many researchers has carried on tests on the contamination performance of insulators under low pressure [1-5]. However, almost all the experiments are carried out under simulate high altitude in an artificial low pressure tank that varies with the actual high altitude conditions. Besides, much attention has been focused on the flashover voltage decrease rather than on the contamination flashover mechanism under low pressure. Thus, it is hard to describe comprehensively the physical processes of contamination flashover in high altitude. The voltage decrease in high altitude has to be qualitatively attributed to the decline of the air breakdown strength [4, 6] and arc VI characteristic [4, 5, 7-10].

In this paper, contamination tests on the insulator model are carried out under the actual altitude. Using the high speed camera synchronized with the voltage & current acquisition system, the AC arc propagation feathers are recorded and investigated. Through comparing the difference of elongation condition under different altitudes, the reasons why contamination flashover voltage decreases under low pressure are discussed. The arc propagation conditions are also analysed in the paper.

2 EXPERIMET SETUP AND METHODS

2.1 Test facilities

The experiments are carried out in Tibet High Altitude Test Base, Tibet with altitude of 4300m and in CEPRI (China Electric Power Research Institute), Beijing of 50m above sea level. The inner structure of fog chamber in Tibet is shown in Figure 1. High voltage is supplied through the wall bushing with the rated voltage of AC 330kV, DC ±250kV.

Figure 1: Fog chamber in Tibet. The size is 9m (width)×9m (length)×11m (height).

The AC supply in Tibet is capable of providing an output of up to 200kV, the system schematic is shown in Figure 2.

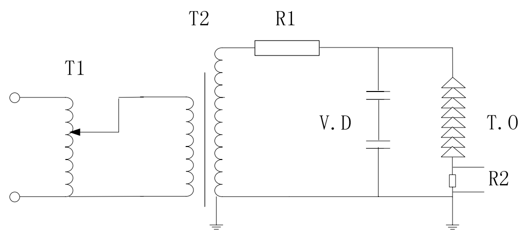

Figure 2: Schematic of 200kV AC supply.T1, voltage regulator, 10kV/0~10.5kV, 1000kVA; T2, power frequency testing transformer, 10kV/200kV, 1000kVA; R1, protective resistance, 5kΩ; V.D, capacitive voltage divider; T.O, test sample; R2, sampling resistance.

The test facilities in Beijing are same with that described above except for the air pressure. So, there is no need to repeat.

2.2 Test sample

The flashover of contaminated insulators is complex due to the apparent random nature of dry bands appear, arc formation and contamination layer wetting. The complex geometric shape of real insulators makes it difficult to completely record the progress of arc propagation. So, the plane triangular model is selected here to investigate the mechanism of AC arc propagation under low pressure, as shown in Figure 3. The base material is glass.

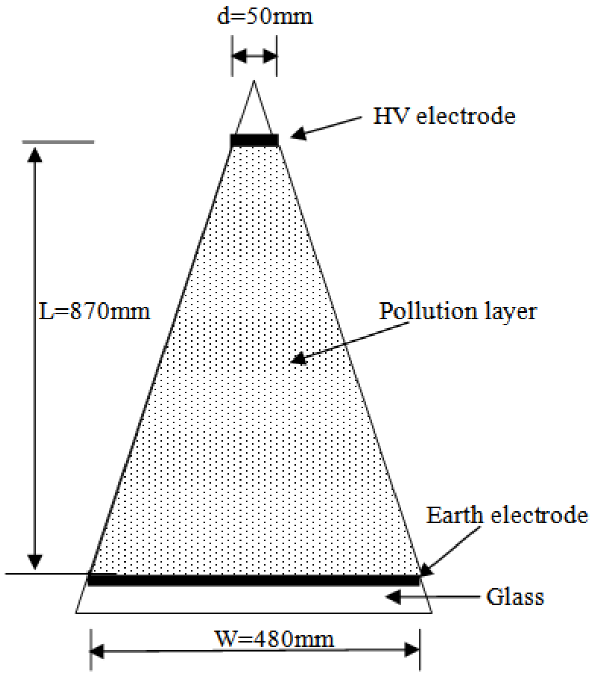

Figure 3: Plane triangular contaminated sample. L refers to the leakage distance; W and d refer to the length of electrode.

2.3 Test procedure

The solid layer method is used in the present study. Specific slurry which is consisted of a certain quality of NaCl, kaolin powder and distilled water is uniformly coated onto the glass surface in Figure 3. The contamination layer has an ESDD of 0.05 mg/cm^2 and a NSDD of 1.0 mg/cm^2 in this research.

While the layer is dried, lay the sample horizontally across two support insulators, with the pollution layer upward to simulate the arc appeared in the upper surface of real insulator. The arrangement of the test sample and high speed camera is illustrated in Figure 4.

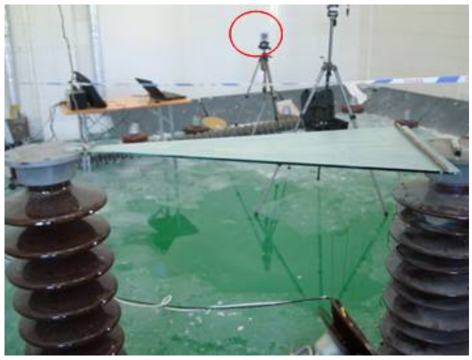

Figure 4: Experiment set up，the red circle shows the high speed camera

In the interest of discharge over the wet contaminated surface, it is significant to obtain as clear as possible photograph of the arc propagation using high speed camera. External consideration should be taken while select the way to wet pollution layer and apply voltage. Because the fully filled fog in the chamber used in artificial pollution tests to wet pollution layer would reduce the visibility too bad to record the arc process clearly.

So, a special wetting method is adopted. That is to spray distilled water onto the pollution surface before experiment, even though it may be thought crude and not precise in the standard artificial pollution tests. After the pollution layer becomes ‘saturated’ with water, which is indicated by the surface conductivity to reach a maximum value, the test voltage is applied.

Then, increase the applied voltage at a certain rate, until flashover occurs. The real time voltage and current are recorded by the acquisition system running in the computer as well as the arc length obtained from the high speed camera. The definition and measurement of the arc length, *x*, are illustrated in Figure 5. The arc elongation induced by rising up would not be considered for simple.

Though the wetting and voltage conditions applied to the test sample are different from the insulators under operating condition, the arc propagation mechanism is the similar. So the conclusions obtained in this experiment are reasonable to represent the actual process in real insulators.

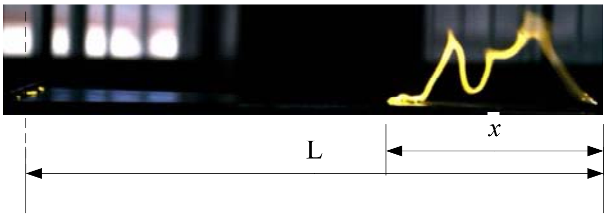

Figure 5: Measurement of the arc length. High voltage electrode is on the right hand side, with arc propagating from right to the left.

3 RESULTS AND DISCUSSIONS

Figure 6 gives the changes of arc length and current before flashover. When the voltage is applied to the test sample, there is current flowing through the wet layer. The distribution of the current is non-uniform due to the specified geometry of the model. The current density is high at the narrow sections near the HV electrode in Figure 3, where dry bands firstly form. Since almost all the voltage appears across the dry bands, the voltage gradient concentrates obviously, if exceeds the spark over voltage of the air gap, air breakdown occurs and maybe lead to stable partial arc if the source power is enough. As the voltage increasing, the partial arc will propagate, with current increasing respectively, as shown in Figure 6.

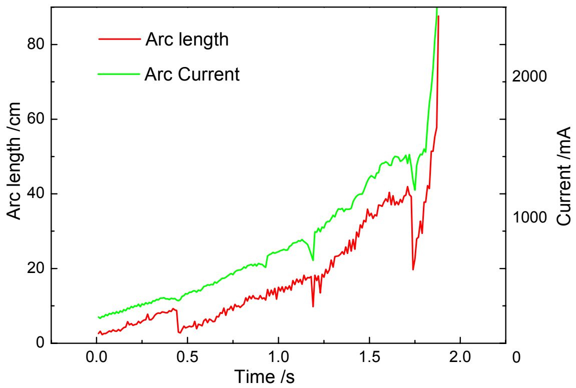

Figure 6: Arc length and current before flashover

It is shown that the arc would not continuously elongate over time. It may develop, stagnate or retreat. Thus, the saw-tooth waveform of the arc length appears in Figure 6. For a certain length of arc, if the power absorbed from the source is enough to maintain the burning arc, it would stagnate; if additional condition for propagation is also satisfied, the arc would develop. Otherwise, the main arc column will rise up by the force of buoyancy together with its voltage increasing. The power needed to sustain burning will increase up to a maximum value depended on the source. If the length exceeds the critical value, then the heat loses from the arc column will exceeds the energy supplied by the source and the high temperature arc channel begin to cool down rapidly together with the decrease of the conductivity. It is impossible to sustain the arc, and then a new arc will take place between contamination layer and the electrode at a shorter distance. That is why the arc becomes short suddenly in Figure 6.

Few researchers have noticed the importance of arc propagation condition in literatures, but thought the maximum value of sustaining voltage as the critical flashover voltage [11-13]. To investigate the difference of propagation conditions under different altitude, the relationship between the arc length and voltage as well as current would be presented and analysed as follows.

3.1 Arc length vs voltage

Figure 7 gives the relations between the arc length and the applied voltage in peak value. The solid lines are calculated theoretically through the equation deduced in [12] which can be expressed as

$$U_{cx} = (1+\frac{1}{n})(nxA)^{\frac{1}{n+1}} R(x)^{\frac{n}{n+1}} \qquad (1)$$

Where: U_{cx} is the critical sustaining voltage (peak value) while the arc length is x;

A ,n is the constant of arc;

$R(x)$ is the residual resistance of pollution layer.

Under low pressure, the constants of arc will be influenced. The effect can be expressed as

$$A = A_0 (p / p_0)^m \qquad (2)$$

Where: A_0 is at the altitude of 0m

p is actual air pressure in kPa

p_0 is the air pressure at 0m in kPa

m=pressure index

The residual resistance can be calculated as [14],

$$R(x) = \frac{1}{\sigma}\int_x^L \frac{dz}{w(z)} \qquad (3)$$

Where: σ is conductivity of layer.

z is the distance from high voltage electrode

$w(z)$ is the width of test model at position z.

In the present calculation, the following values are adopted: A_0=140, n=0.67 [12]; m=0.3 [4, 7], p=59.3kPa at H=4300m. σ=80μs.

The basic view of above derivation hold in [12] is firstly proposed by Obenaus in 1958 [15] that consider the pollution surface as local arc in series with residual resistance. There is a minimum voltage to sustain a certain length of arc, U_{cx}. And the voltage, varying with arc length, has a maximum value which is supposed as the flashover voltage by many researchers [11-13].

Since the voltage is increasing continuously, it is reasonable to consider the voltage as the critical value for a particular length of arc. However, a certain disagreement can be found from the comparison between the experimental results and the calculation shown in Figure 7.

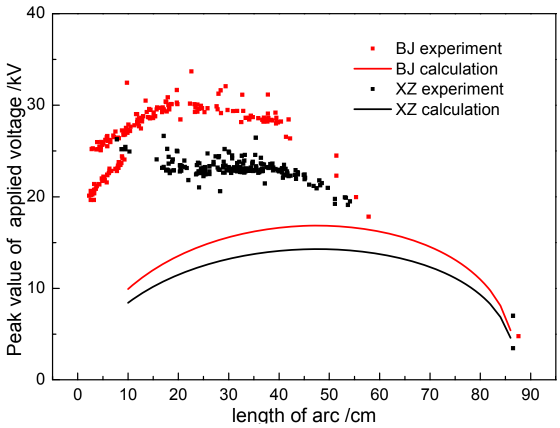

Figure 7: The arc length against applied voltage. ‘XZ’ represents Tibet and ‘BJ’ for Beijing.

For a given arc length, the experimental voltage is much higher than the theoretical one. It is indicated that the propagating arc may be not under the critical condition which demonstrate that the actual voltage is greater than the sustaining value. So, we can get a reasonable assumption that not only the sustaining voltage, but also the propagation conditions should be satisfied for arc to move over the wet surface. Thus, the opinion that thought the maximum value of sustaining voltage as the flashover voltage would be lower than the actual value which has already been proved in [8] that the experimental flashover voltage is 3 times of the calculated value at 101 kPa and 1.8 times at 13 kPa.

Besides, the experimental results demonstrate that the voltage needed in high altitude is lower than that in sea level to sustain the same length of arc which is agree with the calculation. But the degree of experimental voltage decrease is larger which indicate that not only the arc VI characteristic is influenced by the pressure, but also the propagation condition, because only the effects on the arc features are considered in the calculation. These differences also show that the mechanism proposed by Obenaus [15] is not precise to describe the contamination flashover progress. The propagation conditions should also be considered in modelling the phenomena.

3.2 Arc length vs current

Figure 8 gives the tendency of current along with the arc length. We could also suppose the experimental current is the critical sustaining value for the given arc length in the progress of increasing voltage. The lines are calculated as follows [12]

$$I_{cx} = [\frac{nxA}{R(x)}]^{\frac{1}{n+1}} \qquad (4)$$

Where: I_{cx} is the critical sustaining current (peak value) while the arc length is x;

It is noticed that the current would increase with the arc length and would be smaller in high altitude. The tendency is agree with calculated. But great differences between experiment and calculation show that the assumption that the current is the critical sustaining value is not valid. The actual current is much larger. Thus a similar deduction with voltage can be obtained that the current should be greater than the sustaining value to achieve a certain level to make the arc propagate ahead.

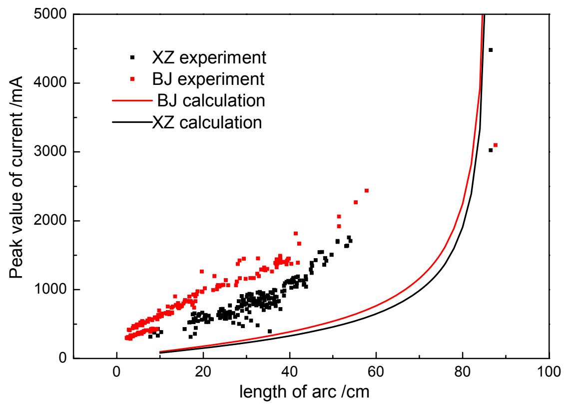

Figure 8: The current against arc length. ‘XZ’ represents Tibet and ‘BJ’ for Beijing.

The calculated current under different pressure show little difference which is not the same with experiments. It also reveals the complicated effects on the surface discharge induced by the pressure through the current aspect. That is why the flashover voltage always decline much greater than expected that has been pointed out in [4] that the calculated pressure index is 0.2 while the actual value ranges from 0.4 to 0.7 for real insulators.

4 CONCLUSION

The measurements of arc length during pollution experiments on triangle model as well as voltage and current are carried out in both Tibet (high altitude) and Beijing, some interesting conclusion can be obtained as follows:

1) At high altitude, the voltage to maintain a certain length of arc is lower than that at lower altitude, the current is smaller, respectively.

2) During the propagation of arc, the current and voltage applied is greater than the critical sustaining value. So, the extinguish voltage is just the necessary condition not the sufficient one.

3) The declination of arc VI characteristic is not the only reason for the decrease of pollution flashover voltage under low pressure.

5 ACKNOWLEDGMENTS

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