Experiments and Analysis of Sand Dust Flashover of the Flat Plate Model

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ABSTRACT
The influence of sand dust on the electrical discharge characteristics of outdoor insulation has drawn worldwide attention. Based on tests on the typical flat plate model, this paper presents research on the flashover characteristics of outdoor insulation in sand dust environment under ac and dc voltages, by means of which the effects of wind velocity, charge of sand particles, sand deposit on insulator and moisture content of sand particles on the flashover process are obtained. The test environment of the flat plate model is classified into sand-wind and sand deposit environments. In the sand-wind environment, wind velocity has remarkable influence on the ac and dc flashover voltages of the flat plate model while the sand and the charge of sand particles have little influence. In the sand deposit environment, the ac and dc flashover voltages of the flat plate model are influenced by the sand deposition density and the moisture content of sand particles. Moreover, according to the record of the flashover process and the calculation of the change of the electric field distribution during this process, the flashover mechanism is analyzed, which shows that the region without sand and the leakage current play important roles in the flashover of the flat plate model in the sand dust environment.

Index Terms - Sand dust, flat plate model, flashover characteristics, flashover mechanism, charge.

1 INTRODUCTION

In recent years, there are a few reports on frequent outdoor insulation accidents caused by sandstorms or sand dust weather in Egypt [1, 2], Saudi Arabia [3-10], China [11], etc. In sandstorm-struck areas, scholars have noticed the electric field and the electromagnetic interference phenomenon caused by sandstorms [12-18]. As a result of the charge transfer caused by sand friction, the charged sand particles can form space charge regions which can have an effect on the discharge characteristics of air gaps and insulators [1-11]. Therefore, the study of outdoor insulation in the sand dust environment may provide a theoretical basis for the insulation design and safety operation in sand dust areas.

Recently, some experimental researches have been carried out on the discharge characteristics of outdoor insulation in sandstorm and sand dust environments. The results show that wind and sand dust have remarkable effects on the discharge characteristics of insulators [1]. Charged sand particles can reduce the flashover voltage of insulators, depending on the electric charge amount of sand particles. Meanwhile, wind velocity in sand dust weather also contributes to the flashover voltage of insulators. The flashover voltage of insulators increases with the increase of wind velocity until it reaches a saturation value [1]. The discharge of the air gap mainly depends on the sand dust deposited on the electrode rather than the floating sand dust [6-10]. As the arc propagates along the surface of insulators, the deposited sand may have an effect on the flashover characteristics [1, 2]. However, these findings are far from meeting the requirements of outdoor insulation design in the sand dust environment, and little is known about the discharge mechanism of sand deposited insulators. Besides, the difference between the flashover characteristics of insulators under ac and dc voltages should be investigated, which motivates the research in this paper.

Based on the flashover tests on the flat plate model, this paper reports on studies of the flashover characteristics and the discharge process of the flat plate model under ac and dc voltages and puts forward the conclusions about the influence mechanisms of factors such as wind velocity, electric charge, and sand, etc. on the flashover process in sandstorm and sand dust environments, which provides a theoretical basis for insulation design in sandstorm and sand dust environments.

2 TEST EQUIPMENT AND METHOD

2.1 SIMULATION DEVICE OF SAND DUST ENVIRONMENT
Sand dust weather is generally classified into floating dust, blowing sand, and sandstorm. This classification is based on wind velocity and visibility. The test system built in the laboratory can simulate several kinds of sand dust weathers by...
regulating wind velocity and the charge on sand particles. This helps to analyze the discharge process and mechanism under different sand dust weathers.

In this paper, two kinds of sand dust models are discussed as follows.

2.1.1 CASE 1: SAND-WIND ENVIRONMENT
In this case, the surface flashover characteristics of insulators in sand dust weather are studied, which mainly focuses on the influence of both wind and sand dust. The test device is shown in Figure 1.

2.1.2 CASE 2: SAND DEPOSIT ENVIRONMENT
As a result of sand dust weather, sand dust can be deposited on insulators, which possibly affects the flashover voltage. Tests in this case aim at studying this effect and relevant mechanism. In this case, the wind sand device in Figure 1 is removed and the sand is uniformly placed on the flat plate model.

The test device in Figure 1 includes the main structure and an axial fan of 2.5 kW, which can regulate the wind velocity from 0 to 10 m/s. The main structure is supported by a metal holder, connecting a hopper and a channel. The channel is made of glass for convenience of observation. In front of the test device, there is a charged galvanized metal-grid which can charge the sand particles. The device can simulate sand dust weather with a certain wind velocity and a certain amount of electric charge on the sand particles. The sand samples, ranging from 0.10-0.32 mm in diameter, were collected from Ningxia Shapotou Desert. The MS6250 digital anemometer is used for measuring the wind velocity with a range of 0-20 m/s and an uncertainty of +/- 0.1 m/s.

2.2 TEST CIRCUIT
The electrical test circuit is shown in Figure 2. The rated capacity is 100 kVA, and the rated current is 1 A. The range of the input voltage is 0-400 V, and that of the output voltage is 0-100 kV. The test sample is a flat plate model which is shown in Figure 3. The high voltage electrode set on the glass plate is a cylindrical copper one with a 50 mm diameter. The glass plate has a size of 600 mm × 600 mm × 10 mm, which is grounded on the edge.

2.3 SIMULATION OF ELECTRIC CHARGE ON SAND
In actual sand dust weather, sand particles can easily be charged as a result of the friction between them and the ground bed. To charge the sand particles in this test, some methods are used as recommended in [1]. A charged galvanized metal-grid is installed at the exit of the wind-sand tunnel as shown in Figure 1. The charge amount of sand particles can be regulated by the applied voltage on the net.

The charge measurement schematic is shown in Figure 4, which is an ordinary method for measuring the charge-to-mass ratio. When the charged sand particles hit the metal net, the electric charge flows into the ground through the circuit of the metal net, leading to a micro current. According to the measured micro current and the mass of sand particles during a certain period of time, the average charge-to-mass ratio can be calculated.
3 FLASHOVER CHARACTERISTICS OF FLAT PLATE MODEL IN SAND-DUST ENVIRONMENT UNDER AC VOLTAGE

3.1 EFFECT OF WIND VELOCITY ON FLASHOVER CHARACTERISTICS

To obtain the effects of the wind velocity, $v$, and the sand on the flashover characteristics of the flat plate model separately, the tests in the environment of Case 1, sand-wind environment, are carried out under two conditions. One is wind-and-no-sand condition and the other is wind-and-sand condition. The sand particles are not charged and form a sand dust mass concentration of 5-10 g/m$^3$. The relationship between the ac flashover voltage, $U_{\text{f(ac)}}$, and $v$ is studied under each condition.

Figure 5 shows the effect of $v$ on $U_{\text{f(ac)}}$ under the two conditions when the creeping distance, $d$, is 60, 100, and 140 mm respectively. With the increase of $v$, $U_{\text{f(ac)}}$ under the wind-and-no-sand condition increases accordingly, but the growth rate decreases. This can be explained by the arc being blown longer by the wind, which increases the difficulty for the arc to propagate and makes the arc more likely to extinguish. However, the effect of the wind on the arc becomes less significant as $v$ increases, which shows the limitation of such effect. This phenomenon shows that the influence of $v$ on $U_{\text{f(ac)}}$ keeps growing until it reaches a peak value, and then remains the same even if the wind gets stronger.

![Figure 5](image)

Figure 5. Relationship between the ac flashover voltage of the flat plate model and the wind velocity.

Figure 5 also shows that $U_{\text{f(ac)}}$ under the wind-and-sand condition is only a little less than that under the wind-and-no-sand condition. Considering the uncertainty of the voltage measurement during the tests, $U_{\text{f(ac)}}$ under the two conditions can be seen as the same. Compared with the effect of $v$ on $U_{\text{f(ac)}}$, the effect of the sand on $U_{\text{f(ac)}}$ is not significant. The possible reason for this phenomenon is that a small quantity of sand particles attached on the plate cannot have a significant effect on the ac flashover characteristics of the flat plate model.

3.2 EFFECT OF ELECTRIC CHARGE OF SAND PARTICLES ON FLASHOVER CHARACTERISTICS

To determine the effect of the electric charge of sand particles on the flashover process, the flashover tests under the condition of charged sand particles in the environment of Case 1 are carried out with various charge amounts of sand particles. Figures 6 and 7 show the flashover test results when the sand particles are charged with positive and negative charges respectively. During the tests, $v$ is regulated to 3 m/s, the sand dust mass concentration is 5-10 g/m$^3$ and $d$ is 80, 100, 120, and 140 mm, respectively. The $r_{q,m}$ in the two figures refers to the charge-to-mass ratio of sand particles.

![Figure 6](image)

Figure 6. Relationship between the ac flashover voltage of the flat plate model and the positive charge of sand particles.

![Figure 7](image)

Figure 7. Relationship between the ac flashover voltage of the flat plate model and the negative charge of sand particles.

From Figures 6 and 7, it can be concluded that when $r_{q,m}$ ranges from 30 nC/kg to 150 nC/kg, there is no significant change of $U_{\text{f(ac)}}$. The reason is that the charge of sand particles is small and cannot have a significant effect on $U_{\text{f(ac)}}$ while the effect of the high voltage applied on the flat plate model is much obvious. The additional space electric field strength caused by the charge of sand particles is small so that it can only affect the electromagnetic signal of communication system [16].

3.3 EFFECT OF DEPOSITED SAND ON FLASHOVER CHARACTERISTICS

To determine the effect of the deposited sand on the flashover voltage of the flat plate model, the flashover tests in the environment of Case 2 are carried out. The tests can show the influences of the sand deposition density, $\sigma_s$, and the moisture content of sand particles, $\eta$, on $U_{\text{f(ac)}}$.

Figure 8 shows the relationship between $U_{\text{f(ac)}}$ and $\sigma_s$. It can be found that with the increase of $\sigma_s$, $U_{\text{f(ac)}}$ appears to be a curve, initially decreasing and then going up. When $\sigma_s$ is kept at a relatively low value, which is less than about 50 mg/cm$^2$, $U_{\text{f(ac)}}$ is less than that of a clean flat plate model. It reaches a minimum value when $\sigma_s$ is 12.5 mg/cm$^2$. Figure 9 shows that there is a positive correlation between $U_{\text{f(ac)}}$ and $\eta$ under the same value of $\sigma_s$.

When the sand particles are exposed to a high humidity environment, which changes the moisture content of sand particles and the mechanical forces between different sand
particles and between sand particles and the plate, the flashover process appears to be different from that of the dry sand. The relationship between $U_{f\text{(ac)}}$ and $\eta$ is shown in Figure 10 when $d$ is 140 mm and $\sigma_r$ is 30 and 50 mg/cm$^2$, respectively.

Figure 8. Relationship between the ac flashover voltage of the flat plate model and the sand deposition density.

Figure 9. Relationship between the ac flashover voltage of the flat plate model and the creeping distance.

Figure 10. Relationship between the ac flashover voltage of the flat plate model and the moisture content of sand particles.

Figure 11. Relationship between the dc flashover voltage of the flat plate model and the wind velocity.

Test results in Figure 11a also show that when the sand dust mass concentration is 2.5-5 g/m$^3$ and the sand particles are not charged, the positive flashover voltage, $U_{f\text{(dc+)}}$, under the wind-and-sand condition is higher than that under the wind-and-no-sand condition. With the increase of $v$, $U_{f\text{(dc+)}}$ reaches a maximum value and then decreases. This is related to the sand deposition density on the flat plate. A certain amount of sand particles with $\sigma_r$ of about 15 mg/cm$^2$ are deposited on the surface of the model when $v$ is small (2-4 m/s), and $U_{f\text{(dc+)}}$ increases until it reaches the maximum value. However, when $v$ is more than 4.0 m/s, the large-sized sand particles are blown away from the surface of the flat plate. And only some small-sized sand particles can be deposited on the surface of the plate. Meanwhile, the wind blows the arc and disperses the charged particles, and the flashover voltage decreases.

4 FLASHER CHARACTERISTICS OF FLAT PLATE MODEL IN SAND-DUST ENVIRONMENT UNDER DC VOLTAGE

4.1 EFFECT OF WIND VELOCITY ON FLASHER CHARACTERISTICS

Figure 11 shows the relationship between $v$ and the dc flashover voltage of the flat plate model, $U_{f\text{(dc+)}}$, in the environment of Case 1 when $d$ is 40 and 60 mm respectively. Test conditions are also classified into wind-and-no-sand and wind-and-sand conditions. From Figure 11, it can be concluded that $U_{f\text{(dc+)}}$ under the wind-and-no-sand condition also increases with the increase of $v$. This phenomenon can be also explained by the reason for the effect of $v$ on $U_{f\text{(ac+)}}$. 
Test results in Figure 11b show that the negative flashover voltage, $U_{f(d-c)}$, under the wind-and-no-sand condition is higher than that under the wind-and-sand condition, especially when $d$ increases from 40 mm to 60 mm. Moreover, $U_{f(d-c)}$ increases with the increase of $v$. This polarity effect is also a special phenomenon of the dc flashover characteristics in the sand dust environment. The effect of sand on $U_{f(dc)}$ is different from that on $U_{f(ac)}$, which needs further research, especially on the difference between the co-effect of wind and sand on $U_{f(dc)}$ and $U_{f(ac)}$.

4.2 EFFECT OF ELECTRIC CHARGE OF SAND PARTICLES ON FLASHOVER CHARACTERISTICS

Figures 12 and 13 show the relationship between $U_{f(dc)}$ and the electric charge of sand particles with a sand dust mass concentration of 2.5-5.0 g/m$^3$ in the environment of Case 1 when $v$ is 8 m/s. Test results in Figures 12 and 13 show that when $q,m$ ranges from 30 nC/kg to 150 nC/kg, there is no significant influence of $q,m$ on $U_{f(dc)}$. This is the same with the influence of $q,m$ on $U_{f(ac)}$. That is to say, the electric charge of sand particles has little effect on the flashover voltage of the flat plate model.

![Figure 12. Relationship between the dc flashover voltage of the flat plate model and the positive charge of sand particles.](image)

![Figure 13. Relationship between the dc flashover voltage of the flat plate model and the negative charge of sand particles.](image)

4.3 EFFECT OF DEPOSITED SAND ON FLASHOVER CHARACTERISTICS

Figures 14 and 15 present the relationship between $U_{f(dc)}$ and $s$ in the environment of Case 2. With the increase of $s$, $U_{f(dc)}$ decreases at first and then increases. However, the increase is very small compared with the decrease at the beginning of the curves shown in Figure 14. $U_{f(dc)}$ reaches its minimum value when $s$ is about 12.5-25 mg/cm$^2$. That is, when $s$ is more than 25 mg/cm$^2$, the effect of $s$ on $U_{f(dc)}$ is stable. Figure 15 shows that under the positive dc voltage, the trend is opposite. $U_{f(dc)}$ reaches its maximum value when $s$ is about 12.5-25 mg/cm$^2$. Both the increase and the decrease of $U_{f(dc)}$ are obvious. This is different from the phenomenon that $U_{f(dc)}$ remains stable after it decreases at the beginning.

There is an obvious polarity effect of the flashover characteristics under dc voltage. Test results in Figures 14 and 15 show that when the plate is clean, $U_{f(d-c)}$ is higher than $U_{f(d+c)}$. When $s$ is 6.25 mg/cm$^2$, $U_{f(d-c)}$ is a little higher than $U_{f(d+c)}$. When $s$ is 12.5, 18.75, 25, 37.5 and 50 mg/cm$^2$, $U_{f(d-c)}$ is less than $U_{f(d+c)}$. Moreover, the difference between the flashover voltages under the two kinds of polarities becomes larger with the increase of $d$. This is the same with the polarity effect of the flashover voltage of polluted insulators and ice-covered insulators. The difference value between $U_{f(d-c)}$ and $U_{f(d+c)}$ reaches the extreme value when $s$ is 18.75 mg/cm$^2$. The corresponding values are 42%, 52%, 56% and 50%, when the creeping distance is 30, 40, 50 and 60 mm, respectively.

![Figure 14. Relationship between the negative flashover voltage of the flat plate model and the sand deposition density.](image)

![Figure 15. Relationship between the positive flashover voltage of the flat plate model and the sand deposition density.](image)

Figure 16 shows the relationship between the moisture content of sand particles, $\eta$, and $U_{f(dc)}$ when $s$ is 25 and 50 mg/cm$^2$ and $d$ is 50 mm. Test results in Figure 16 show that under the positive and negative dc voltage, $U_{f(dc)}$ decreases with the increase of $\eta$. The effect of $\eta$ on $U_{f(dc)}$ is different from that on $U_{f(ac)}$. During the flashover process, the partial arc first occurs at the edge of the high-voltage electrode and the grounding electrode, and then the final surface flashover occurs as a result of the continuous increase of the applied voltage. This is very similar to the pollution flashover process. Under the condition that $\eta$, $s$, and $d$ remain the same respectively, $U_{f(dc)}$ is less than $U_{f(ac)}$. This polarity effect is the same as the one of pollution flashover [19-20]. That is to say, the moisture content of sand particles plays an important role in the dc flashover process, but the sand has little effect on the dc flashover process.
5 FLASHOVER MECHANISM OF FLAT PLATE MODEL IN SAND DEPOSIT ENVIRONMENT

5.1 FLASHOVER PROCESS OF FLAT PLATE MODEL IN SAND DEPOSIT ENVIRONMENT

Only photographs of the flashover process in the case of sand deposit environment were taken because of the poor visibility of the test system in the sand-wind environment and the positive effect of this environment on the flashover voltage of the flat plate model. All the photographs were taken by a high speed HG-100k camera. The flashover process of the flat plate model under ac voltage is investigated in order to explain the effect of deposited sand on the flashover process. According to the above test results, $\sigma_c$ is classified into two types: one is $25 \text{ mg/cm}^2$, and the other is $250 \text{ mg/cm}^2$.

Figure 17 shows the ac electric field distribution along the flat plate model with uniform sand distribution under the applied voltage of 30 kV. From Figure 17, it can be found that the electric field of the flat plate model is typically non-uniform. It can also be found that it is only near the high voltage electrode that the tangential electric field strength is more than the normal electric field strength.

Figure 17. Electric field distribution of the flat plate model before test.

When $\sigma_c$ is kept at a relatively low value, as shown in Figure 18, the normal component of the electric field strength, $E_n$, near the high voltage electrode causes the charged particles in the air to strike the plate surface covered by deposited sand particles, and thus charged the sand particles. The charged sand particles are pushed forward by the tangential electric field strength, $E_t$. The region without sand is formed as shown in Figures 18a-18d. This region keeps expanding, and the electric field strength on it is different from that on the region covered by sand. This causes partial discharge initiation in the region without sand. When the applied voltage increases beyond the critical value, some bright purple arcs alternatively occur on the surface of the region without sand. The arc extinguishment and reignition can be clearly observed during the test. The sand on the arc channel can be moved upwards by the strong normal force of the electric field. This results in the appearance of new regions without sand, as shown in Figures 18e-18h. With the rise of the applied voltage, the regional arc expands to the grounded electrode and leads to the complete flashover with a yellow arc channel, as shown in Figures 18i-18l.

Figure 18. Flashover process of the flat plate model with $d=140 \text{ mm}$ and $\sigma_c = 25 \text{ mg/cm}^2$.

Figure 19. Flashover process of the flat plate model with $d=100 \text{ mm}$ and $\sigma_c = 250 \text{ mg/cm}^2$.

Figure 19 shows the flashover process of the flat plate model when $\sigma_c$ is kept at a relatively high value. With the increase of the applied voltage, the partial discharge takes place at the micro air gaps near the high voltage electrode and the grounded electrode, as shown in Figures 19a-19d. The arc charges the sand particles near both electrodes. These charged sand particles are driven bouncing by the strong normal force of the electric field, as shown in Figures 19e-19f. As the applied voltage rises beyond the critical value, the arc turns yellow and gets longer rapidly, as shown in Figures 19g-19l. When the arc connects the two electrodes, the flashover takes place at the micro air gaps near the high voltage electrode and the grounded electrode, as shown in Figures 19a-19d. The arc charges the sand particles near both electrodes. These charged sand particles are driven bouncing by the strong normal force of the electric field, as shown in Figures 19e-19f. As the applied voltage rises beyond the critical value, the arc turns yellow and gets longer rapidly, as shown in Figures 19g-19l. When the arc connects the two electrodes, the flashover takes...
place. The bouncing sand particles over the arc channel make a big noise during the discharge process. This phenomenon becomes more outstanding as $\sigma_r$ increases.

From the flashover test of the plate model under dc voltage, it can also be found that there is a difference between the flashover processes with various sand deposition densities. The reason for this difference is the same as the one for the difference between the ac flashover processes with various sand deposition densities. However, the reason for the difference between the change trend of the flashover voltage under negative and positive voltages needs further research.

### 5.2 FLASHOVER MECHANISM OF FLAT PLATE MODEL IN SAND DEPOSIT ENVIRONMENT

During the flashover process, the region without sand is formed and has a remarkable effect on the flashover process. Figure 20 presents a comparison between the models before and after the test under ac voltage when $d$ is 140 mm and $\sigma_r$ is 25 mg/cm$^2$. It can be found that the region without sand, which affects on the flashover process, appears during the flashover process.

![Contrast chart before and after flashover of the flat plate model with $\sigma_r=25$ mg/cm$^2$.](image1)

As mentioned above, the electric field distribution along the flat plate model with deposited sand is non-uniform. Driven by the normal electric force, the charged particles keep striking the plate surface. When $\sigma_r$ is kept at a relatively low value, $E_t$ near the high voltage electrode is large enough to push the sand particles moving along the surface of the flat plate, thus leading to the formation of the region without sand. The shape of the region is related to $\sigma_r$. When $\sigma_r$ is kept at a relatively high value, the tangential electric force cannot drive the sand particles. Therefore, there is no clear region without sand when the initial discharge takes place with a high deposition density.

The region without sand can change the former electric field distribution because the permittivity of the sand is larger than that of the air. Figure 21 shows the partial electric field distribution along the first 10 mm part of the flat plate with $d$ of 100 mm, the applied voltage of 30 kV, and the deposited sand particles placed uniformly with a 2 mm region without sand. It can be noticed that after the formation of the region without sand, $E_t$ in this area increases, and $E_i$ out of the area decreases accordingly. As a result of the change of the dielectric property, $E_n$ of the interface also increases remarkably. The maximum value of $E_n$ increases from 2.64 to 4.53 kV/mm.

As the electric field strength in the region without sand is larger than that out of the region, a partial discharge is more likely to take place in the region. The partial discharge in the region without sand is shown in Figure 22 when $d$ is 120 mm and $\sigma_r$ is 50 mg/cm$^2$. The region without sand can obviously be found near the high voltage end. Therefore, when the effect of the electric field distortion on the flashover process is stronger than the hindering effect of the sand on the flashover process, the flashover voltage is lower than that under the clean condition.

![Electric field distribution of the flat plate model.](image2)

Under the dc voltage, the electric field distribution is determined by the conductivities of the air and the sand. However, the conductivity of the sand is also larger than that of the air. Therefore, when the region without sand is formed by the electric force, the electric field distribution is also changed. The partial discharge initiates in the region without sand and leads to the final flashover with the increase of the applied dc voltage.

### 5.3 FLASHOVER MECHANISM OF FLAT PLATE MODEL WITH VARIOUS MOISTURE CONTENTS IN SAND DEPOSIT ENVIRONMENT

The mechanical forces between different sand particles and between the sand particles and the flat plate become larger as the moisture content of sand particles increases. When the voltage is applied at the first stage, it is difficult for the wet
sand particles to form the region without sand. This trend is more obvious when the moisture content of sand particles increases. Figure 23 shows the ac flashover process of the flat plate model with \( d \) of 140 mm, \( \sigma_s \) of 50 mg/cm\(^2\) and \( \eta \) of 2.7%. Figure 24 shows the leakage current during the last 2.5 seconds of the flashover process.

From Figure 24, it can be found that due to the small amount of the moisture content, the leakage current is also small during the whole process. The sand is easy to be dried, which causes the leakage current to be stable despite the increase of the applied voltage. With the heating effect of the leakage current, some sand particles near the high voltage electrode are dried and pushed aside by the electric force, but the total amount of these sand particles is small. When the applied voltage increases beyond the critical value, some bright purple arcs alternatively occur on the surface of the flat plate, as shown in Figures 23a-23h. During this stage, some pulses of the leakage current can be found in Figure 24 with the time interval of 1.6-2.0 s. With the increase of the applied voltage, the arc expands to the grounded electrode and results in the complete flashover along the surface with a yellow arc channel, as shown in Figures 23i-23l. This is quite the same as the flashover process of the dry and clean flat plate.

Figure 25 shows the ac flashover process of the flat plate model with \( d \) of 140 mm, \( \sigma_s \) of 50 mg/cm\(^2\) and \( \eta \) of 10%. Figure 26 shows the leakage current during the last three seconds of the flashover process. According to Figure 26, when \( \eta \) is 10%, the leakage current obviously changes during the flashover process. The flashover process can be divided into four stages according to the change of the leakage current. When the peak value of the leakage current is 15-60 mA within the time interval of 0-0.5 s shown in Figure 26, there is no obvious arc, as shown in Figure 25b. When the peak value of the leakage current increases to 60-180 mA within the time interval of 0.5-1.8 s shown in Figure 26, some partial purple arcs occur near both electrodes, as shown in Figure 25c. As the applied voltage keeps rising, the arc goes through the process of extinguishment, reignition and development, as shown in Figures 25d-25f. At the same time, the peak value of the leakage current increases to 180-450 mA within the time interval of 1.8-2.7 s shown in Figure 26. When the applied voltage goes beyond the critical value, the arc develops into flashover, as shown in Figures 25g-24h, the peak value of the leakage current increases to 500 mA at the time point of 2.8 shown in Figure 26.

According to the flashover tests, the leakage current increases with the increase of \( \eta \). When \( \eta \) is at a small value, the dry area can be formed due to the heating effect of the leakage current. Thus, the region without sand near the high voltage electrode can be formed. Bouncing dry
sand particles can cover the space over the arc channel. When \( \eta \) is at a high value, the adsorption force between different sand particles increases and the region without sand is hardly formed. As the applied voltage rises, a remarkable increase of the leakage current can be found and there are no obvious bouncing sand particles. The whole flashover process is the same as the pollution flashover process.

Under the dc voltage, the flashover voltage decreases with the increase of \( \eta \), which also proves that \( \eta \) and the leakage current play important roles during the flashover process. However, when \( \eta \) is at a small value, there is a difference between the ac and the dc flashover voltages. This shows that the effect of \( \eta \) on the dc flashover is more important than that of the sand on the ac flashover.

6 CONCLUSIONS

According to the experimental research and the mechanism analysis of the sand dust flashover of the flat plate model, some conclusions are put forward as follows:

1. \( U_{f(ac)} \) and \( U_{f(dc)} \) increase with the increase of \( \nu \) under the wind-and-no-sand condition, but the increase rate decreases with the increase of \( \nu \). The effect of sand on \( U_{f(ac)} \) is not significant compared with that of \( \nu \) on \( U_{f(ac)} \). \( U_{f(dc)} \) under the wind-and-sand condition is less than that under the wind-and-no-sand condition. With the increase of \( \nu \), \( U_{f(dc)} \) reaches a maximum value and then decreases under the wind-and-no-sand condition, and \( U_{f(dc)} \) under the wind-and-sand condition is higher than that under the wind-and-no-sand condition.

2. When the charge amount of sand particles in the sandwind environment changes within a certain range, it has little effect on the flashover voltage of the flat plate model under both ac and dc voltages.

3. When the dry sand particles are deposited on the surface of the flat plate model and the sand deposition density increases, there exist the minimum values for \( U_{f(ac)} \) and \( U_{f(dc)} \) respectively and a maximum value for \( U_{f(dcc)} \). When the wet sand particles are deposited on the surface of the flat plate model, there exists a maximum value for \( U_{f(ac)} \). However, \( U_{f(dcc)} \) and \( U_{f(dcc)} \) keep decreasing with the increase of the moisture content of sand particles with \( U_{f(dcc)} \), less than \( U_{f(dcc)} \). The leakage current plays an important role during the flashover process.

4. Sand deposition has an effect on the flashover process of the flat plate model. When the sand deposition density is at a small value, the region without sand is formed during the flashover process. The partial discharge initiates on the region without sand, thus reducing the flashover voltage. When the sand deposition density is relatively high, the obvious region without sand cannot be formed during the flashover process and the flashover voltage increases.

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REFERENCES


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