Influence of Forest Fire Particles on the Breakdown Characteristics of Air Gap

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ABSTRACT

The frequent forest fires become a serious threat to the performance of transmission lines' external insulation. Gap breakdown in forest fire relates to many factors, such asflame temperature, conductivity and particles. Large quantities of smoke (carbonblack) and flying ash are produced during the combustion of vegetation, causing thedielectric strength of gap to decrease drastically. In order to analyze the influence of forest fire particles on the breakdown characteristics of air gap, the experimental setup consisting of a conductor-plane was built to simulate the effect of forest fire particles. At the same time, a theoretical model was developed to analyze the influence mechanism of multiple particles on the discharge characteristics of gap. Experimental results show that, a chain of carbon particles has been formed between flame and conductor by the action of electric field. The gap's insulation strength decreases significantly, which is about 40% of that in the pure air under AC voltage. The particles movement and the breakdown characteristics of air gap have an evident effect of polarity characteristic under DC voltage and the breakdown voltage is reduced to about 29 % of that in the air gap under negative DC voltage. The simulation results show that, the electric field distribution between conductor and plane become uneven, and the distortion degree of the elongated particle to the background electric field is not related to the distance between particles with high-voltage electrode. According to the electric field diagram, it is obvious that the particles make the background electric field distortion, and the maximum field strength increased by about 100%. More close to the conductor, the greater electric field strength is at the both ends of particles.

Keyword : - *Forest, ash, breakdown characteristics, electric field distortion, particle-triggered discharge, polarity effect fire, particle.*

1. INTRODUCTION

In recent years, forest fires near the transmission lines have been reported to be a serious threat to the safe and reliable operation of power grids . Phase to phase and phase to earth flashovers caused by forest fires have been reported in many countries, such as China, Africa, Mexico, Brazil and Canada. The dielectric properties of air is drastically reduced due to the reduction of air density resulting from the high temperature of the flame, charged particles produced by the thermal and chemical ionization, and the elongated solid particles and ash carried by the convection current associated with combustion and electric field force. The average power frequency breakdown voltage gradient in a 3 m conductor-plane configuration under various fire sources are shown in Table. Compared to gasoline and alcohol fires, the breakdown voltage is the minimum when thegap is bridged by the flame of sugar cane leaves, mainly caused by the floating particles and ash generated within the gap by the sugar cane leaves, indicating that the forest fire particle shave a great effect on the dielectric properties of an air gap [9]. The historical statistical data indicated that the type of vegetation which can cause transmission lines tripping are mainly sugarcane, straw, reed, thatch etc.. Large quantities of smoke (carbon black) and flying ash are produced during the combustion of the vegetation, causing the dielectric strength of gap to decrease drastically.

2. EXPERIMENTAL METHOD AND PROCEDURE

The experimental particles and ash were produced by the vegetation including fir branch, straw, and thatch. The AC and DC voltage breakdown experiments under different vegetation
particles and gap length were carried out. The experimental procedure is as follows:
(1) According to the Figure 2, the gap length was adjusted to a experimental length by adjusting the simulation conductor and the vegetation were stacked on the metallic support,
(2) Igniting the vegetation, then began to apply voltage and increase voltage after the flame was combustion stable, and the motion trajectory and triggering discharge of particles in
the fire gap had been observed by a camera.
(3) When the height of flame was zero, in order to observe the influence of particles and ash on the insulating properties of air gap, the voltage was applied again until the gap was
breakdown or the applied voltage was close to the rated voltage of the testing transformer. The waveforms of leakage current were recorded in the experiments, and the experimental
process was also recorded by a camera at the same time.

2.1 EXPERIMENTAL ARRANGEMENT

The experimental arrangement of the gap discharge experiments for the simulation of forest fires which includes a testing transformer, connected to the conductor through a 10 kΩ damping resistance. The rated voltage of the testing transformer is 100 kV. The actual
conductor was simulated by a hollow cylindrical conductor with a 2 cm diameter, having a 1 m length and stress control spheres at both ends. The applied AC (the frequency is 50 Hz),
DC voltage and leakage current were measured with a capacitor divider, a resistor voltage divider and shunt R0, respectively.

2.2 EXPERIMENTAL RESULTS

a lot of particles have been produced when the flame is closed to the high-voltage conductor, and the carbon particles are attracted or rejected by the conductor under the action of electric field. Because the effect of electric field distortion near the particles is increased, the small gap between particle and electrode, particle and particle are shortcircuited by the local arc when the particles are in the vicinity of the electrode, which has an intense light emission and athick channel shape and is thought to have high conductivity.

3. DISCUSSION

Forest fire is a kind of diffusion flame, and the volatile ingredients produced by solid vegetation are mutual diffusion and reaction. If the smoke and particles in the flame have been exposed a relatively long time in the environment above 1000 K, which can be burned completely, and the particles out of the reaction zone will become smoke or ash. In the actual forest fire accidents, the vegetation is general incomplete burning. Hence, large amounts of ash and particles may be produced, and the triggering discharge of particles and ash has a “multiplier effect” in the line gap due to the function of the thermal buoyancy of flame .The particles will make the electric field distortion in the vicinity of them, which can also adsorb charge and trigger discharge when the particles move into the gap. The charged mechanism of particles in the electric field is related to the size of particle. In order to analyze the particle-triggered discharge mechanism conveniently, assuming the particle is spherical in this part. When the radius of particle is greater than 0.5 μm, the electric field charged is dominant. While the radius of particle is less than 0.2 μm, the diffusion charged plays a leading role. When the radius of particle is in between, two kinds of charged mechanism are very important and must be considered at the same time. In the normal conditions, the size of particles (carbon black) and ash are greater than 0.5 μm in forest fires. Hence, the way of particle charged is mainly the electric field charged. The distortion degree of the electric field depends on the size of particle. When the numbers of the electric fluxline terminate on the particle are reduced to zero, the particle is in saturated charged condition, and the electric field distortion will reach the maximum.

3.1 DISCHARGE MECHANISM OF MULTIPLE GAPS UNDER PARTICLES

The particle-triggered discharge under the condition of fir fire A large number of particles havebeen produced in the process of vegetation combustion, and the particles will form particle-chain in the air gap, which canbe seen from Figure 7. The discharge will develop between particle and particle step by step, and the streamer can be

captured by the particle to form arc when the streamer is in the process of closing to the next particle . The arc formed by triggering discharge between the particle and high-voltage conductor, particle and particle will bridge a part of gap distance under the action of electric field. The gap bridged by the arc become more and more with the increase of appliedvoltage, then lead the dielectric strength of gap to reduce greatly.

The typical discharge process due to the particles bridge the gap can be seen. After applied the voltage, the particles are attracted to the gap and upward movement to the high-voltage conductor. The discharge in the minor gap between top particles and electrode has appeared. With the voltage increasing, more micro-gaps are bridged by themicrodischarges between particle and particle.

4. CONCLUSIONS

In order to study the influence of the forest fire particles and ash on the breakdown characteristic of the conductor-plane gap, the simulation experiments have been carried out with the different vegetation particles in this paper. The discharge mechanisms of the forest fire particles are analyzed and the results are summarized as follows.

1) Large amounts of particles and ash will be produced during the forest fire of transmission line corridors, and the average movement velocity of the particles in fire gap is faster than air gap under the action of heat convection and electric field force, which can be reached to about 2.25 m/s.

2) The size of the particles and ash has a big difference after the vegetation burning, and the thatch particles have a bigger influence on the dielectric properties of gap than other
vegetation particles. The dielectric strength of gap will reduce greatly when the length of carbon particles is longer and the weight is lighter. When the forest fire particles move toward to the gap due to the electric field force, the AC breakdown voltage of gap can be reduced to about 40% of that in the air gap under the standard atmosphere. The more carbon particlesin the gap, the greater decline the dielectric strength will be

3) The movement and the breakdown characteristics of the particles in the gap have an evident polarity effect under DC voltage. The breakdown voltage of gap is reduced to about 29
% of that in the air gap under the negative polarity voltage, and the leakage current of gap under the negative polarity voltage is much larger experimentally than that of positive
polarity voltage in the same experimental condition, which is the same with the movement characteristics of the particles. The particles size, type, weight and the streamer development around the particle are the main reasons.

4) The particles in the gap will cause the local electric field distortion, and the distortion range is increased obviously after the particles charged. The bigger the size of the particle and the greater charged volume from the flame, the stronger the electric field distortion will be in the gap. The threshold electric field strength of particle-triggered discharge in the gap will be declined greatly under the condition of forest fire. The
range of particle-triggered discharge can be reach to 8.83*D*, which is three times as large as the uncharged particle and it is easier to form chain-discharge and short most gap distance.

5) The discharge characteristics of the particles in the fire gap is obviously different with the pure air gap, and the triggering discharge of the particles and ash has a “multiplier effect” under fire conditions, which can lead to a sharp decline in the dielectric strength of gap. However, the discharge mechanism of the particles under the action of the flame still need to be further researched.

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