CHARACTERISTICS OF STREAMER PROPAGATION ALONG INSULATION SURFACE: INFLUENCE OF DIELECTRIC MATERIAL AND SHED CONFIGURATION

WANG LIMING, MENG XIAOBO, MEI HONGWEI, GUAN ZHICHENG

Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China
E-mail address:wanglm@sz.tsinghua.edu.cn

ABSTRACT

Research on dynamics of streamer propagation along the different dielectric materials and shed configurations under a uniform electric field was presented in this paper. Experiments were carried out in a three electrode arrangement consisting of a parallel-plane gap (10 cm), stressed by negative DC voltage. Streamers were initiated from a sharp point which was set in a shaped receptacle at the center of the lower grounded plane and propagated along the insulation surface. The electric field required for stable streamer propagation and the propagation velocity with electric field sustaining stable streamer propagation were studied. The streamer 'stability' propagation field and velocity depend upon the nature of the dielectric material. Specifically, higher electric fields are required for streamers to propagate along a dielectric material with larger permittivity. The influence of insulator shed on streamer propagation along silion rubber insulation surface was also investigated. The conclusion was that the electric field required for stable streamer propagation and the associated velocity increased/decreased with the rise of the protrusion length of insulator shed.
Key words: Uniform field; Streamer discharge; Dielectric material; Insulator Shed; Three-electrode arrangement

1. INTRODUCTION

Compared with research on the streamer propagation in air, only several articles investigated the streamer propagation along the insulation surface. The researchers found that the electric field required for streamer propagation along the insulation surface is larger than in air alone. They also found the streamer propagates along the insulation surface with a 'fast' and a 'slow' component. However, they had no clear reason why there were lots of differences between streamer propagation in air and along the insulation surface. The researchers got the photographs of a mode with two simultaneous discharges: one in gas and one along the dielectric surface. The infulences of material properties on the streamer discharge had no unanimous conclusions [1]. Consequently, the characteristics of streamer propagation along the different dielectric materials should be studied in depth.

In this paper, the characteristics of streamer propagation in air alone and along different dielectric materials were measured in the three electrode system using three photomultipliers. The streamer 'stability' propagation field, and velocity were measured, which were important in the determination of streamer characteristics. The photographs, showed the path of the streamer propagation in air alone and along the different dielectric material, were taken by ultraviolet camera. The differences between streamer propagation in air and along the insulation surface were investigated deeply. Finally, measurements of streamer propagation electric fields and velocities were made for the various protrusion length of the insulator shed and were compared with the corresponding characteristics of air and cylindrical insulators.

2. EXPERIMENT AND MEASUREMENT

Figure 1 shows the experiment arrangement and measurement system. The three-electrode arrangement was used, consisting of two parallel planes with a gap clearance of 10 cm and a sharp point, which was located in a small aperture with a 10 mm diameter at the centre of earthed plane. The sharp point was set 3 mm above the earthed plane and insulated from it by a PTFE bushing. The negative direct voltage was applied to the upper plane, in this way a uniform electric field was applied to the gap. The cylindrical dielectric material was inserted perpendicularly to the parallel planes, and almost in contact with the sharp point. A positive voltage square pulse with variable amplitude of 0-6 kV and duration of 150 ns was applied to the sharp point to initiate the streamer. The rise and fall times of the square pulse is 10~15ns. The square pulse, which was produced by the discharge of a coaxial line, was monitored via a high voltage probe (Tektronix) that was used to trigger a 4-channel 2 GHz digital storage oscilloscope.

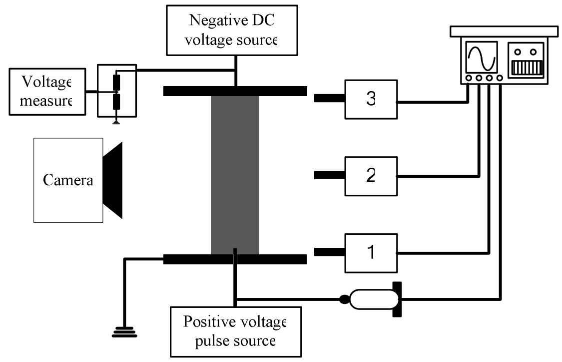


Fig. 1 Schematic of experiment arrangement and measurement equipments

The collisional ionization occurring in the streamer head has a process of photons emission. Therefore, the photomultiplier (PM) can be used to monitor the development of streamer by receiving photons emitted from streamer head. In the paper, three identical battery driven photomultipliers (EMI, 9083B) were used to monitor the streamer progress up to the cathode. Each photomultiplier, with a narrow aperture of width 1 mm and length 20 cm ahead, had a vertical field of view of 3 mm along the axis and was horizontally placed 40 cm away from the axis. The PM 1, PM 2, and PM 3 were directed at grazing incidence to grounded plane, middle position of gap, and the cathode respectively. The outputs of three photomultipliers were displayed simultaneously with the pulse voltage at the sharp point on the screen of oscilloscope.

In experiment, temperature was about 20 ^{o}C, relative humidity was about 60% and air pressure was standard atmospheric pressure. Six dielectric materials shown in Figure 2 were used as the specimens, such as Nylon, Silicone Rubber (SIR), Polytetrafluoroethylene (PTFE), Polymethyl Methacrylate (PMMA), Polyformaldehyde (POM) and Ceramic (CERG). All dielectric materials were smooth and cylindrical shown in Figure 2. Six insulators were also investigated as shown in Figure 3, including: cylindrical insulator, insulators with a shed whose protrusion length is 5mm, 10mm, 15mm, 20mm, 25mm, respectively. The specimens were cleaned with ethanol before the experiments. The characteristic of streamer propagation in air alone was also studied which was regarded as 'reference' for surface streamer.

Fig. 2 Photograph of six kinds of dielectric materials

Fig. 3 Photograph of six kinds of insulators with different shed protrusion length

3. EXPERIMENT RESULTS

3.1 STREAMER PROPAGATION FIELDS

The electric field corresponding to streamer propagation probability of 97.5% was defined as streamer 'stability' propagation fields E_{st} [2]. The probability distributions of streamer propagation in air alone and along six dielectric materials are shown in Figure 4. The electric fields required for streamers propagation along an insulation surface are higher than in air alone. Furthermore, the streamer propagation fields depend upon the nature of the dielectric materials significantly. The relative permittivity value was 5 for nylon, 3.6 for SIR, 3.6 for POM, 3.2 for PMMA, 2.1 for PTFE, and 6.5 for CERG. Hence, the results show that higher electric fields are required for streamers to propagate along a dielectric material with larger permittivity except ceramic.

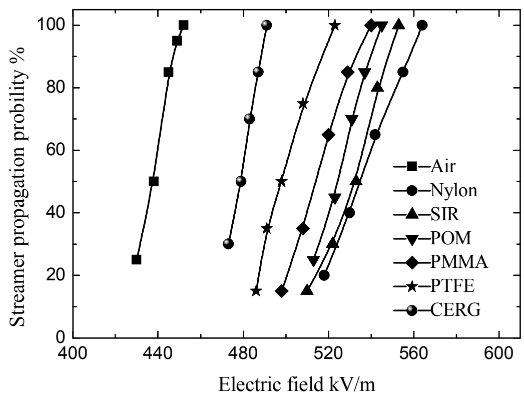


Fig. 4 Probability of streamer propagation as a function of guiding electric field

Figure 5 shows typical distributions of the probability of streamers propagation along cylindrical insulator, along insulator with different protrusion length of shed and in air alone. It indicates an increase in the streamer propagation electric fields for all of the insulators in comparison to air. At the same time, electric fields are significantly higher for streamer propagation along the insulator with a shed than that along cylindrical insulator. Besides, the electric field required for stable streamer propagation increases with the rise of protrusion length of insulator shed. The reason is that there is significant energy absorbed at the shed due to the deposition of charge at the shed or due to the energy required for the streamers to pass over the shed. however, the tangential component of electric field is negligible at the place of shed, so streamer propagation is restrained by the shed of insulator. At the same time, the influence of the shed on the streamer propagation increases with the rise of protrusion length of insulator shed.

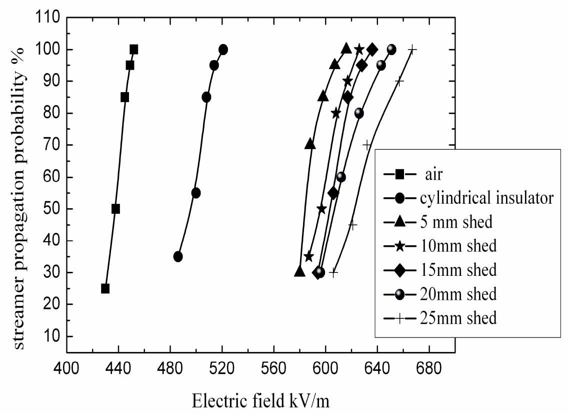


Fig.5 Streamer propagation probability distribution of different insulators and air

3.2 LIGHT EMISSION

Typical oscillograms of signals from three photomultipliers, viewing streamer propagation in air alone are shown in Figure 6 where the guiding field is 500 kV/m. Figure 7 shows the typical photomultiplier signals of streamer propagation along the surface of SIR where the guiding field is 600 kV/m. One peak of light is detected at the cathode by PM 3 as streamer propagates in air alone. However, when it turns to streamer propagation along the dielectric materials, two peaks of light are detected at the cathode by PM3 as the guiding fields are higher than the stability fields, with the delay to the first peak shorter than the second.

Allen first discovered this phenomenon in 1999. However, the 'fast' component and 'slow' component could not be distinguished easily for signal distortion in his paper. It is caused by limiting band width of amplifier used to amplify photomultiplier signals. Therefore, the accuracy of velocities of 'fast' and 'slow' component measured by Allen is also unreliable [3]. In this paper, the band width of amplifier used to amplify photomultiplier signals is 200 MHz, hence, the signal distortion of 'fast' component and 'slow' component is not evident compared with that.

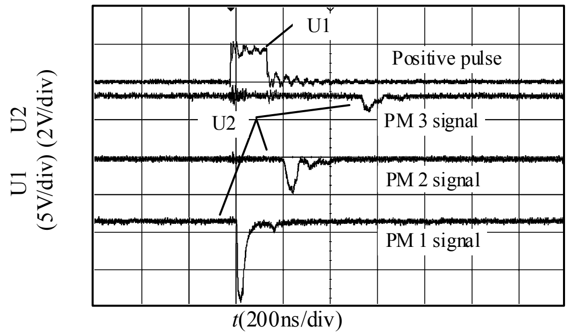


Fig. 6 *Typical photomultiplier signals of streamer propagation in air alone (E=500kV/m)*

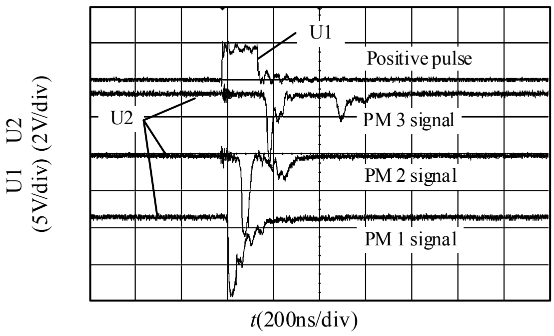
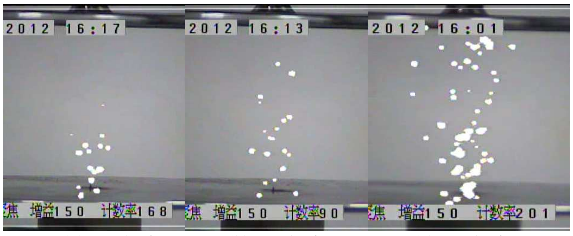


Fig. 7 Typical photomultiplier signals of streamer propagation along the surface of SIR (E=600kV/m)

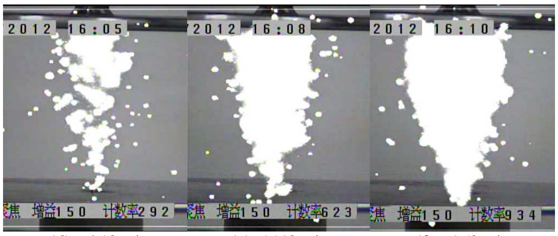
Furthermore, the phenomenon of streamer propagation along the ceramic surface in our paper is a little different with the paper [3]. Allen found that only one component could be detected as streamer propagated along the ceramic surface. It is as same as the phenomenon found by us as the guiding field is low. When the guiding field rises to 656 kV/m, much higher than stability fields, the streamer propagates along the surface of ceramic, consisting of two streamers, that is 'fast' component and 'slow' component.

The photographs of the streamer propagation in air alone and along the different dielectric materials were taken with the 'DayCor@Superb' UV imaging detector made by Ofil Corporation. The UV imaging detection system mainly includes UV imaging lens, UV filter, UV intensified system, CCD, image display, etc. The light emission from streamer was available from a single shot to register clear image, hence, a single propagation process of the streamer was recorded in each photograph. Figure 8 shows the photographs of the streamer propagation in air alone under variable electric fields in the range of 390-720 kV/m. The white spots on the photographs mean the light emission from discharge in this place. The photographs shows that the lateral diffusion due to streamer branching is evident as streamer propagates in air alone.

The photographs of the streamer propagation along the surface of SIR under variable electric fields are shown in Figure 9. The two streamer components are observed distinctly, that is 'fast' component propagating along the surface of dielectric material and 'slow' component propagating in air. Under the low guiding fields, only 'slow' component of streamer can reachs the cathode, while the 'fast' component is so weak and always disappears somewhere. However, the 'fast' component is powerful and can reachs the cathode with higher guiding field.



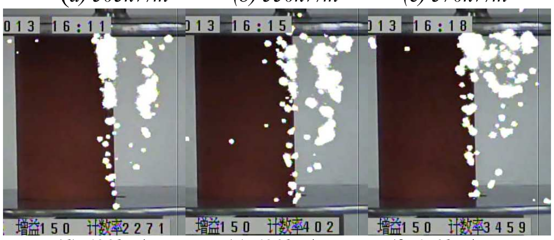
(a) 390kV/m (b) 428kV/m (c) 476kV/m



(d) 581kV/m (e) 661kV/m (f) 716kV/m

Fig.8 Photographs of streamer propagation in air alone under variable electric fields (u=4kV)

(a) 505kV/m (b) 550kV/m (c) 570kV/m



(d) 600kV/m (e) 620kV/m (f) 640kV/m

Fig. 9 Photographs of streamer propagation along the surface of SIR under variable electric fields (u=4kV)

Through the observation of photographs, the result, whether the streamer reachs the upper electrode or not, can be achieved. Therefore, the photographs also can be used to acquire the probability of streamer propagation in air alone or along the dielectric materials. The probability of streamer propagation from the observation of photographs is approximately the same as that from the observation of photomultiplier signals in section 3.1.

3.3 STREAMER PROPAGATION VELOCITY

The streamer propagation velocities were derived from the signal records of photomultipliers. Firstly, the streamer propagation times were measured using the start of the rise of each light signal (Figure 6, 7), thus the corresponding propagation velocities could be calculated. The velocities of streamer propagation along the dielectric materials were measured complexly. Here the velocities derived from the start of the first light peak at the sharp point and the arrival of the first peak at the cathode were regarded as the 'fast' component of the streamers. The velocities derived from the start of the first light peak at the sharp point and the arrival of the second peak at the cathode were regarded as the'slow' component. The velocities of streamer propagation, at stability fields, were defined as streamer 'stability' propagation velocities V_{st}.

The velocities of 'fast' component and 'slow' component as a function of the guiding fields are shown in Figure 11 and 12. It is obvious that the velocity of the streamer propagating in air alone is significantly less than the velocilty of the 'fast' component, and is higher than the velocity of the 'slow' component.

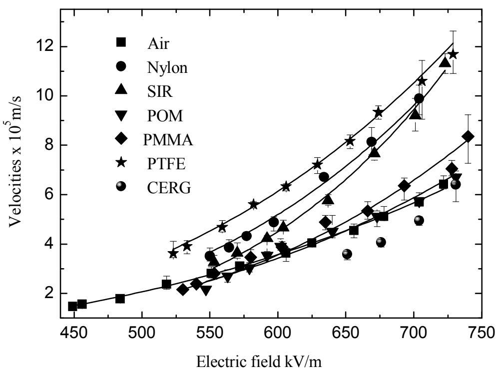


Fig. 11 Velocities of 'fast' component as a function of the electric field (u=4kV)

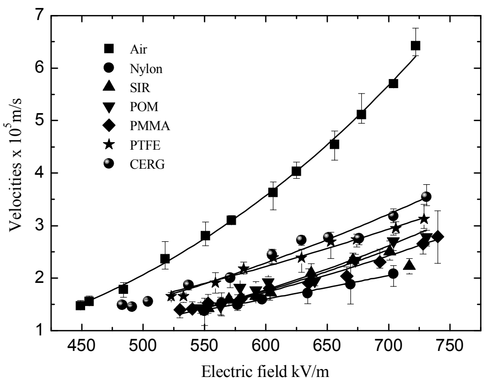


Fig.12 *Velocities of 'slow' component as a function of the electric field (u=4kV)*

The reason is that the velocity of the 'slow' component is hindered by the development of the 'fast' component. The velocity of the 'fast' component depends upon the dielectric materials and increases with electric field obviously, whereas that of the 'slow' component is similar for six dielectric materials and varies slowly with electric field.

The velocities of streamer propagation along insulator with shed are plotted as a function of electric field in Figure 13. It shows that the 'air' component velocity for the insulators with shed is smaller than that for air alone. Also, the velocity is almost equal to that of the 'air' component of the cylindrical insulator under low electric field, but it is higher under high electric field. The reason is that the shed modifies the streamer system resulting in only the 'air' component reaching the cathode, the 'surface' component is resisted at the place of insulator shed, so the influence of 'surface' component on 'air' component is smaller than that for cylindrical insulator. Therefore, the 'air' component velocity for the insulators with shed is higher than that that for cylindrical insulator.

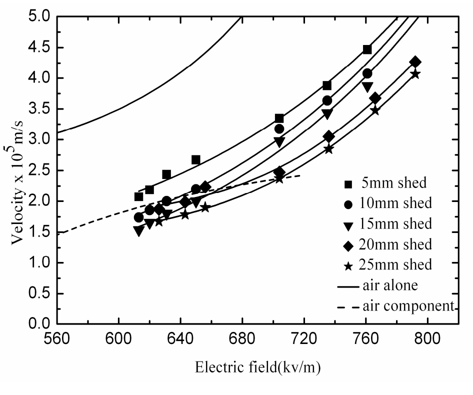


Fig. 13 Velocities of streamer propagation along insulator with a shed as a function of electric field (10cm propagation distance)

4. CONCLUSION

The electric field required for streamer propagation in air alone is less than along the insulation surface. The streamer 'stability' propagation fields depend upon the nature of the dielectric material. Specifically, higher electric fields are required for streamers to propagate along a dielectric material with larger permittivity. There is an increase in the streamer propagation electric fields for all of the insulators in comparison to air alone and the electric fields are significantly higher for streamer propagation along the insulators with shed than that along cylindrical insulator. The electric field required for stable streamer propagation increases with the rise of protrusion length of insulator shed.

The velocity of the streamer propagating in air alone is significantly less than the velocilty of the 'fast' component, and is higher than the velocity of the 'slow' component. The velocity of the 'fast' component depends upon the dielectric materials and increases with electric field obviously, whereas that of the 'slow' component is similar for six dielectric materials and varies slowly with electric field.

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REFERENCES

[1] A. Sobota, A. Lebouvier, N. J. Kramer, E. M. van Veldhuizen, W. W. Stoffels, F. Manders, and M. Haverlag, "Speed of streamers in argon over a flat surface of a dielectric," J. Phys. D Appl. Phys., **vol. 42**, 2009.
[2] N. L. Allen and A. Ghaffar, "The conditions required for the propagation of a cathode-directed positive streamer in air" J. Phys. D Appl. Phys., **vol. 28**, pp. 331-337, 1995.
[3] N. L. Allen and P. N. Mikropoulos, "Streamer propagation along insulating surfaces," IEEE Transactions On Dielectrics And Electrical Insulation, **vol. 6**, pp. 357-362, 1999.