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Study on DC flashover characteristics of plastic sheds in small scale

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Abstract. The statistics of tripping data of transmission lines show that external damage has become the main cause of transmission lines tripping. The foreign object cutting-out, which accounted for 61.8% of the total, was the most common external damage in transmission line. This paper focuses on the DC flashover characteristics of small-scale plastic sheds of greenhouses with distances of 1m and 2m. The results of the study showed that the surface of plastic sheds was less dirty and the average surface conductivity was lower. In the dry condition, it can be regarded as an insulator, and in the case of moisture, however, its insulation resistance is reduced to a megohm level. Under the electric field of 70 kV/m, no flashover occurred in both the wrinkled and the tiled plastic sheds. The flashover voltage per unit length of the wrinkled is about 15%-21% lower than that of the tiled, and wrinkled plastic sheds flash over more easily. As the pole pitch increases, the flashover voltage per unit length decreases, and the flashover voltage per unit length of both the wrinkled and the tiled is reduced by about 30%.

1. Introduction

In recent years, with the rapid development of social economy and the continuous expansion of urban scale, the transmission lines in the outskirts of the city have gradually entered the urban area. Activities such as illegal building of houses and illegal tree planting in power line protection areas have continuously encroached on the line channels. Some towers are even enclosed by the logistics center, warehouses, factories and residential areas. The original line design standard has been unable to meet the current situation. Insufficient distance discharge often occurs, which not only affects the safe operation of power grid, but also poses a serious threat to the safety of construction personnel.

In addition, the construction of basic traffic has been significantly accelerated, and vegetable plastic greenhouses and steel structure greenhouses have been widely promoted, which also increases the possibility of external damage[1-7].

The transmission line of a Power Grid Corp 66kV and above has been tripped 2358 times throughout the year. The main cause of line trips are: lightning strike (1019 times, 43.2%), external force destruction (784times, 33.2%), birds trouble(313 times, 13.3%), wind trouble(114 times, 4.8%) and ice trouble(40times, 1.7%). The main causes for the failure are as follows, external force destruction(436 times, 54.5%), lightning strike(164 times, 20.4%), wind trouble(93 times, 11.6%), birds trouble(29 times, 3.6%) and ice trouble(22 times, 2.7%).

It can be seen from the data of the above-mentioned transmission line trip that external force damage has become the main cause of the tripping and failure of the transmission line.

The line trip caused by external force damage has low recombination power, which is more likely to cause the transmission line to be out of service. The failure of transmission line has changed the structure and operation mode of the power grid in a short period of time, increasing the risk of large-scale power outages.

If the substation switch and relay protection are also defective at the same time, the switch will be rejected and the step-by-step protection action will occur, resulting in power failure of a larger range of equipment, which will adversely affect the safe operation of the power grid [5-7].

External force damage can be divided into floating object, crane hitting line, illegal construction, forests fire, smoke and others according to the type [8-12].

For transmission lines of 500 kV and above, external force damage causes the line to trip 55 times this year, as shown in Table 1. The main cause was floating object, accounting for 61.8% of the total number of external damages.

Table 1. Causes of external damage in transmission lines of each voltage level.

Voltage level	Crane hitting line	Forests fire	Smoke	Floating object	Total
1000kV	0	0	0	1	1
750kV	0	1	0	1	2
500kV	1	15	2	29	47
±400kV	0	0	0	1	1
±500kV	0	2	0	1	3
±660kV	0	0	0	0	0
±800kV	0	0	0	1	1
Total	1	18	2	34	55

There are many vegetable greenhouses growers in Shandong province. Shouguang is famous for greenhouse vegetable growing, and is one of the top 100 economic counties in China. The vegetable planting area has reached more than 800,000 mu, and there are more than 300,000 vegetable greenhouses [13-14]. Plastic shed cloth is often scraped to the wire by the wind. Plastic sheds in greenhouses seriously affect the safe operation of power grids, and pose a huge threat to the safe operation of transmission lines.

The restart time of the DC transmission line is short (about 200ms), and the floating object is easy to cause bipolar blocking. Therefore, it is urgent to study the mechanism of the DC line blocking caused by the plastic sheds of greenhouses, providing a theoretical basis for the subsequent preventive measures.

In this paper, the DC flashover characteristics of plastic sheds of greenhouses are studied, especially for small-scale greenhouse plastic sheds (inter-electrode distances of 1m and 2m), which lays a foundation for the study of flashover characteristics of plastic sheds with large-scale and long gaps.

2. Measurement of contamination degree of plastic sheds of greenhouses

Table 2. Contamination degree of greenhouse plastic sheds.

Samples	ESDD(mg/cm^2)	NSDD(mg/cm^2)
1#-front	0.0019	0.0091
1#-back	0.0015	0.0117
2#-front	0.0010	0.0111
2#-back	0.0011	0.0093
3#-front	0.0011	0.0102
3#-back	0.0013	0.0097
Average	**0.0013**	**0.0102**

The equivalent salt deposit density (ESDD) was measured on the plastic sheds collected in the field. Three areas were selected, and the plastic sheds size of each area was 2m×1m, which were #1, #2, and #3 respectively. The ESDD and non-soluble deposit density (NSDD) were measured in the dissolving and drying method [15-16].

The ESDD and NSDD of the plastic sheds are shown in Table 2.

The ESDD of the plastic sheds is lower, with an average of 0.0013mg/cm^2. The NSDD is 0.0102 mg/cm^2 in average. The ESDD and NSDD of both sides of the sheds are similar. It shows that the surface of the plastic sheds is less polluted and the surface conductivity is low.

3. DC voltage withstand experiment

The DC electrode is two parallel steel pipes with a spacing of 1m. The plastic sheds is placed on the steel pipe(shown in Figure1). The width of the plastic sheds used in this article is 1.5m, and the length is equal to the pole distance.

The DC voltage applied to the sheds is -70kV. As the pole distance of ±800kV DC transmission line is 22.9m typically, the electric field is 70kV/m, which is the electric field in the experiment.

Studies have shown that the voltage of negative flashover is lower than the positive flashover. Withstand time is 2min.The experiment considers four influencing factors of plastic sheds: tiled state, wrinkled state, dry and wet.

(a)Tiled plastic sheds   (b) wrinkled plastic sheds

Figure 1. Plastic sheds in the experiment.

3.1. DC withstand experiment under dry and wet conditions

In the first step, tiled plastic shed at both ends of the electrode. The resistance of plastic shed was tested with a 2500V tramegger under the dry condition, and the result was infinity (supreme tramegger range). When a voltage of -70kV DC was applied, a noticeable corona was heard and no spark was seen.

In the second step, the surface of the plastic sheds was sprayed and wetted, and about 300mL deionized water (conductivity 7μS/cm) was sprayed.

The purpose of spraying the deionized water is not to affect the original dirty state of the plastic sheds. The resistance of plastic shed under the wet condition was 3.5MΩ.

When applying -70kV DC, there was a significant discharge phenomenon. The plastic shed of the two electrodes had a partial discharge, and a local arc was observed. Both ends of the plastic shed were ablated, and water vapor lifted from the surface. After about 20 seconds, the arc went out and the flare disappeared. There was a small amount of burning holes on the plastic shed near the electrode, which corresponded to the position of the arc.

It can be seen that under wet conditions, the resistance of the plastic sheds drops sharply, from infinity to a few megaohms. Partial discharge is more likely to occur near the two electrodes, and a local small arc is generated to ablate the plastic sheds. But partial discharge does not continue to

develop at this time. As the water evaporates, the insulation resistance of the plastic sheds increases and the partial discharge disappears.

3.2. DC withstand experiment under wrinkled condition

A new sample was selected for experiment. The sample was first placed on both ends of the electrode and wetted with deionized water. The spray volume was 300mL. The wet plastic sheds was then tightened to make them wrinkled.

The insulation resistance of the plastic shed was 2MΩ, which was lower than the tiled state. When a voltage of -70kV DC was applied, a significant discharge phenomenon was observed. Partial discharge and arc were observed in the vicinity of the two electrodes, and the plastic shed was ablated.

It could be found that the wet wrinkled plastic shed had lower electrical resistance than the tiled plastic shed. But under the electric field of 70kV/m, the wrinkled plastic shed and the tiled plastic shed did not flashover.

4. DC voltage flashover experiment

Select plastic sheds and cut into samples of 1*1.5m and 2*1.5m respectively for preparation. Wet the plastic shed, and apply a negative DC voltage to the plastic shed until flashover. The flashover voltage value is recorded. The experiment procedure is recorded using a high speed camera.

4.1. 1m electrode distance DC flashover experiment

The distance between the two electrode wires was adjusted to 1 m. The DC flashover experiment of the plastic shed of tiled state and wrinkled state was carried out for three times respectively.

During the experiment, the plastic shed near the poles first appears partial discharge, and the partial discharge develops to form a long partial arc. Finally the arc penetrates and flashover occurs.

The tiled plastic shed is extinguished after flashover, and there are less ablated holes. The wrinkled plastic shed continues to burn after flashover.

(a) Local arc of tiled plastic sheds   (b) Local arc of wrinkled plastic sheds

Figure 2. Plastic sheds flashover experiment with pole pitch of 1m.

The average flashover voltage of tiled shed with 1m electrode distance is 121.8kV, and that of wrinkled shed with 1m electrode distance is 95.9kV.

For plastic shed with 1m electrode distance, the flashover voltage per meter of the wrinkled state is 21% lower than that of the tiled state. The wrinkled plastic shed is easier to flashover.
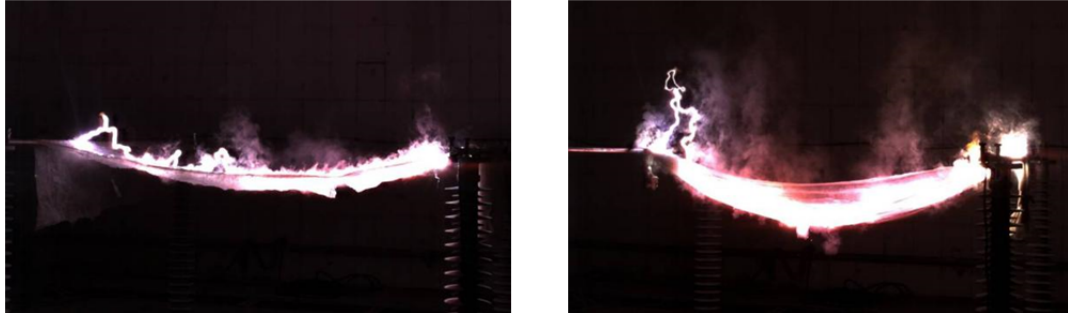
4.2. 2m electrode distance DC flashover experiment

The distance between the two electrode wires was adjusted to 2m. The DC flashover experiment of the plastic shed of tiled state and wrinkled state was carried out for three times respectively.

For tiled plastic shed, it can be seen from Figure 3 (a) that during the experiment, the two electrodes first appeared partial discharge, then develop arc. The arc drifts away from the surface of

plastic shed. With the increase of voltage, the arc was connected, and finally formed a through discharge channel.

For wrinkled plastic shed, the flashover process was similar to the flat state as shown in Figure 3 (b), except that there was a slight arc at both ends of the electrode. Most of the arc channels were located inside the plastic cloth. As the arc was located inside the shed, the heat concentration was not easy to diffuse, and the shed continued to ablate after the arc was extinguished.

| (a) Flashover of tiled plastic sheds | (b) Flashover of wrinkled plastic sheds |

Figure 3. Plastic sheds flashover experiment with pole pitch of 2m.

| (a) Partial discharge appearing | (b) Partial arcs forming | (c) Partial arc developing |

| (d) Flashover occurring | (e) Arcs extinction |

Figure 4. Plastic sheds flashover experiment with pole pitch of 2m
(Top view).

The 2m plastic shed flashover experiment overlooking photo shows the whole process of DC flashover more intuitively.

In the first stage, as shown in Figure 4 (a), obvious partial discharge occurs and the partial discharge concentrates near the two electrodes.

In the second stage, as shown in Figure 4 (b), the number of partial discharge points increases and some intense partial discharges develop into small partial arcs.

In the third stage, as shown in Figure 4 (c), the local small arc develops and expands, and the arcs of the two electrodes develop simultaneously. The arc intensity (length, width, etc.) is similar. The arcs of the two electrodes gradually approach each other, and the arc distance decreases. It should be noted that for the strongest arc, the position of the arc is constantly changing with the formation of the dry zone, not fixed at a certain point, as can be seen from the comparison between Figure 4 (b) and Figure 4 (c).

In the fourth stage, as shown in Figure 4 (d), two electrodes arcs penetrate through, forming discharge channels and flashover. Corresponding to the previous stages, the final arc channel is not necessarily the location where partial discharge first occurs in the first stage, nor is it necessarily the location where the arc is most intense in the second or third stages.

The final discharge channel has certain randomness, and the arc does not focus on ablating a fixed part of the plastic shed. So the plastic shed is not easy to burn out in a short time.

In the fifth stage, as shown in Figure 4 (e), the arc goes away and the arc gradually dies out.

The average flashover voltage of the tiled plastic shed with a distance of 2m is 164kV, and the flashover voltage per meter is 82kV. The average flashover voltage of the wrinkled plastic shed with a distance of 2m is 139kV, and the flashover voltage per meter is 69.5kV.

4.3. Factors affecting the flashover voltage of plastic sheds

4.3.1. The effect of unfolded state (tiling, wrinkles). The average initial insulation resistance in the tiled state is 4.5MΩ, and the average value of the initial insulation resistance in the wrinkled state is 6.4MΩ. Compared with the wrinkled state, the tiled plastic shed is more in contact with the two electrodes, and the insulation resistance value is low.

For plastic sheds with a distance of 1 m, the flashover voltage per meter in the wrinkled state is about 21% lower than that of the tiled. For a plastic shed with a distance of 2m, the flashover voltage per meter of the wrinkled state is about 15% lower than that of the tiled. Therefore, the wrinkled plastic shed is easier to flash. There are three main reasons for this:

First, although the average value of the initial insulation resistance in the tiled state is low, the tiled plastic shed is fully exposed to the air in the flashover process,, and the thermal effect of the partial discharge causes the moisture on the plastic surface to evaporate more easily, resulting in insulation resistance becoming big.

Second, the electric field of the shed in wrinkle state is more uneven than the tiled, and the local field is strong, which is beneficial to the occurrence of partial discharge.

Third, in wrinkled state, the arc channel is mainly concentrated in the relatively closed space inside the plastic shed. The ions generated by the discharge are not easy to diffuse, and the de-freeing is insufficient, which is more conducive to the development of the arc [17].

4.3.2. The effect of electrode distance. In the tiled state, the flashover voltage per meter of the 1m distance is 121.8kV, and the flashover voltage per meter of the 2m is 82kV, which is reduced by 32.7%.

In the wrinkled state, the flashover voltage per meter of 1m is 95.9kV, and the flashover voltage per meter of 2m is 69.5kV, which is decreased by 27.5%.

It can be seen that as the electrode distance increases, the flashover voltage increases nonlinearly, and the flashover voltage per meter decreases. The flashover voltage per meter of the tiled state and the wrinkle state decreases similarly, at about 30%.

The relationship between the DC flashover voltage of the plastic shed and the electrode distance is consistent with the law that the air gap or the breakdown voltage of the insulator increases nonlinearly with distance.

5. Conclusions

(1) The plastic shed of the greenhouse has a low degree of contamination, and the average surface conductivity is small. In the case of dryness, it can be regarded as an insulator, but in the case of moisture, the insulation resistance is reduced to the mega-ohm level.

(2) Under the electric field equivalent to 70kV/m, the wrinkled plastic shed and the tiled plastic shed will not flash over.

(3) The flashover voltage per meter of the wrinkled state is about 15%-21% lower than that of the tiled. The wrinkled plastic shed is more likely to flash over.

(4) As the electrode distance increases, the flashover voltage per meter decreases. The flashover voltage per meter in the tiled state and the wrinkled state decreases by about 30%.

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