RESEARCH REPORTS

EFFECTS OF INSULATING FILM ON NEGATIVE POINT CORONA AT ATMOSPHERIC PRESSURE

MASAYUKI IEDA, GORO SAWA and UKICHI SHINOHARA

Department of Electrical Engineering

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1. Introduction

Recently, the importance of corona resistance of solid insulating materials has been appreciated as it is one of the limiting factors in the eventual breakdown of electric insulation. Thereafter, methods of corona resistance tests and the study of the deterioration mechanism caused by corona discharge has been developed. Although it has been tried in recent studies to measure the quantities related to corona discharge, *i.e.*, charge magnitude or energy of corona discharge and number of corona pulses attacking solid insulator, and to estimate quantitatively the corona resistance from the relation between these quantities and time to electric breakdown of the solid insulator[1], little is known of the nature of corona discharge in such discharge space as with the solid insulating film. In this paper, results are reported on the negative point corona in the discharge space involving an insulating film, while for the usual negative point to plane corona without any insulating film in discharge space, detailed analyses have been made by L. B. Loeb[2], W. N. English[3], M. R. Amin[4] and H. Enjoji[5][6], etc. Generally, the inserted insulating film makes a large disturbance of space charge due to the charge accumulated on it. From this point, such investigation as reported here is considered to be useful for reexamination of the results reported so far about the effects of space charge on the negative point corona.

2. Experimental

When alternating current voltage is applied to the electrode system mentioned above, the observed phenomena are rather complicated, because of various reasons, for instance, space charge magnitude and its distribution being dissimilar in each positive and negative half cycle. For these reasons and in order to make an easy comparison with the usual negative point corona, direct current voltage was applied. While five kinds of samples were used as inserted insulating films, experiments were mainly made on the Sample No. 1.

Symbols and dimensions of the electrode system are shown in Fig. 1. Fig. 2 also shows the photograph of the electrode system. Most experiments were made with hemispherically-ended platinum wire of 0.5 mm diameter as a nega-

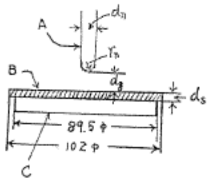


FIG. 1. Geometrical arrangement of electrode system. A: Point electrode (Platinum or copper), B: Insulating film, C: Plate electrode (Brass).

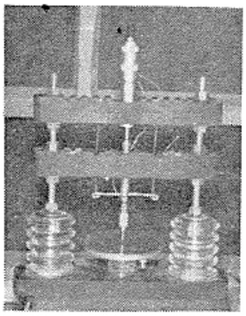


FIG. 2. Photograph of electrode system.

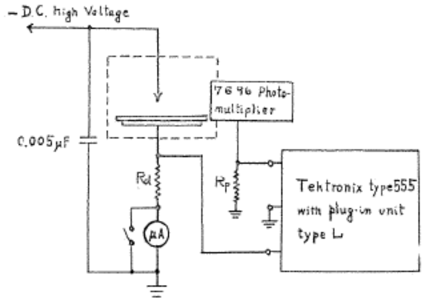


FIG. 3. Schema of measuring circuit.

TABLE 1. Insulating Film Inserted

Sample No.	Composition	Volume Resist. (ohm-cm) 13°C	Dielectric Const. (21°C, 50 c/s)	dgc 1″ (mm), r_n= 0.25 mm
1	PVC*(100**)+DOA***(45**)	1.6×10^{12}	4.9	1.4
2	PVC (100)+DOA (35)	1.4×10^{13}	4.9	1.5
3	PVC (100)+DOA (25)	1.9×10^{14}	5.0	1.5
4	PVC (100)+TCP! (25)	2.8×10^{16}	5.1	1.4
5	Polyethylene	$>10^{16}$	2.3	1.4

* Polyvinyl chloride, ** Parts by weight, *** Plasticizer (Di-octyl adipate), ! Plasticizer (Tri-cresyl phosphate), ″ Refer to Chap. 4 and 7.

tive point electrode and some others with copper wires of 1.0 and 3.99 mm diameter. The circuit for measuring of both current pulses and photon pulses emitted from the corona is given in Fig. 3.

3. Voltage (V)-Current (I) Characteristics

V-I characteristics without the insulating film are given in Fig. 4 as a parameter of gap-length. It is seen that at constant applied voltage, the shorter the gap-length, the larger the mean current. On the contrary to above, those with the insulating film, as shown in Fig. 5, do not appear to show any systematic behavior which might furnish in the relation between V and I. However, when the abscissa in the figure is converted from voltage to gap-length as shown in Fig. 6, some features become explicit. That is one of the features apparent for the case with the insulating film is that the mean current never increases even when the gap-length is decreased, while there is considerable increase of it for the case without any film.

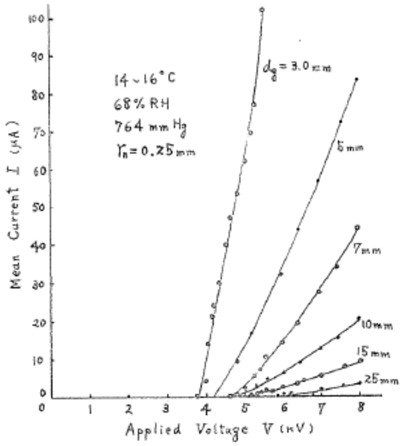


FIG. 4. *V-I* Characteristics in a discharge space without an insulating film.

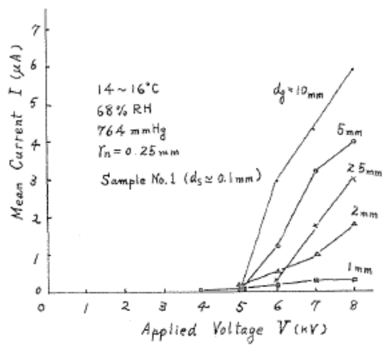


FIG. 5. *V-I* Characteristics in a discharge space involving an insulating film.

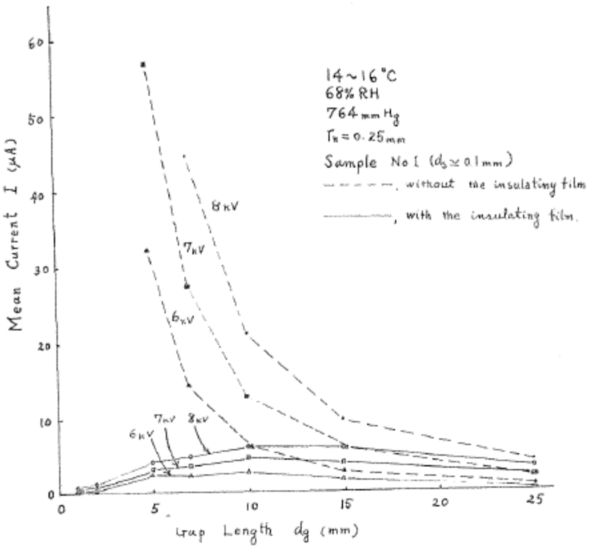


FIG. 6. Mean current as a function of gap-length.

It was pointed out[7] that the mean current caused by negative corona, so called "Trichel pulses," depends upon the decay speed of negative ion space charge formed near the point electrode and its magnitude is proportional to corona pulse repition rate. In order to examine whether these facts are valid or not for the special discharge space shown in Fig. 1, the relation between mean current (I) and pulse repitition rate (n) was investigated. Fig. 7 shows these results; at the gap-length above about 2 mm, the plots of log I and log n fall on a simple straight line with a slope of 45°, which means the relation $J \propto n$, independent of existence of film and of gap-length. It is understood from

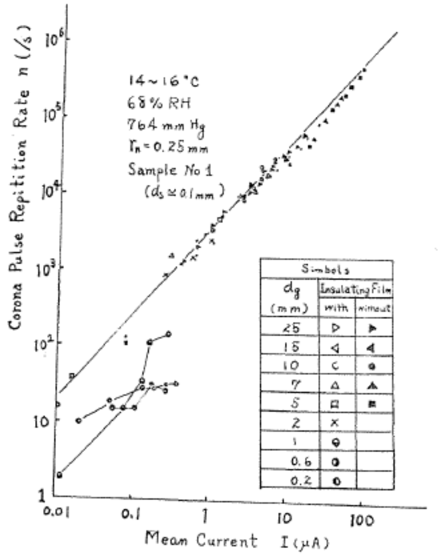
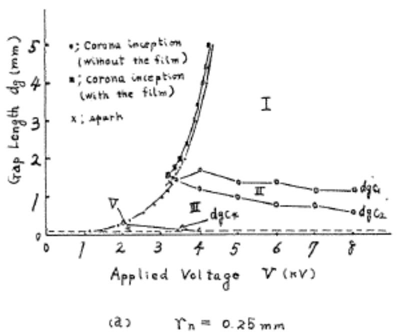
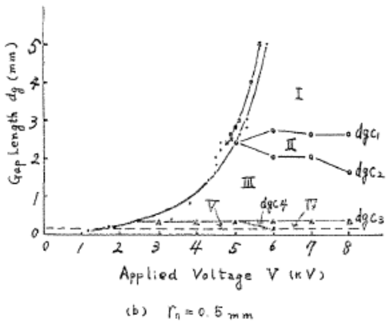


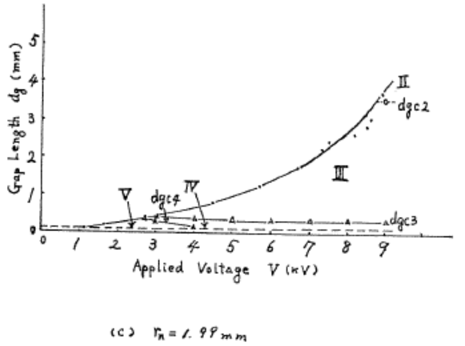
FIG. 7. Relation between mean current and corona pulse repitition rate.

these facts that in this region of gap-length, the insulating film inserted into the discharge space has no effect on the basic mechanism of the negative corona pulse formation, but only influences the decay speed of negative space charge after the ionization action is choked off. On the other hand, the $n-I$ characteristics below about 2 mm of gap-length differ from those mentioned above, and the mean current in this case is larger than that in the former case in spite of the same pulse repitition rate. It is suggested that the charge magnitude involved in each corona pulse is not the same in both regions and especially the inserted film plays an important role in the formation of each corona pulse in the region below about 2 mm of gap-length.

4. Wave Form of Electrical Pulse of Corona







Sample No 1 ($d_s \simeq$ 0.1 mm) 10.1 ～ 15.0°C 60～78% RH
755 ～ 765 mm Hg.

FIG. 8. Discharge regions defined by wave form of corona current pulse in dg-V plane.

In order to clarify the effect of insulating film on the basic mechanism of ionization process, wave forms of electrical pulses were examined over a wide range of gap-length. It was found from the forms of observed electrical pulses that the discharge form is divided into five regions with different wave form in the *dg*-*V* plane as shown in Fig. 8. Typical oscillograms in each region are shown in Fig. 9. As an example, the result will be explained below for the case of 0.25 mm radius point. Three principal regions I, III, and V, may be roughly distinguished and in each boundary between I and III and between III and V, there exists a boundary region II and IV, respectively.

(Region I): The wave form is nearly the same as that of familiar Trichel pulse in the absence of film and has the time duration of about 0.2 μs (Fig. 9 a and a′). Accordingly, the influence of inserted film appears only in pulse repitition rate which determines mean current and this region corresponds to the portion where the plots of log I and log n fall on the straight line in Fig. 7.

(Region III): In this region, the corona pulse having a special wave form appears and the relation between log I and log n is dissimilar to that in the region I. As shown in Fig. 9 b and b′, the electrical pulse has a long plateau at the wave tail following an initial spike. The time duration of this plateau is in the range of about one to a few tens μs.

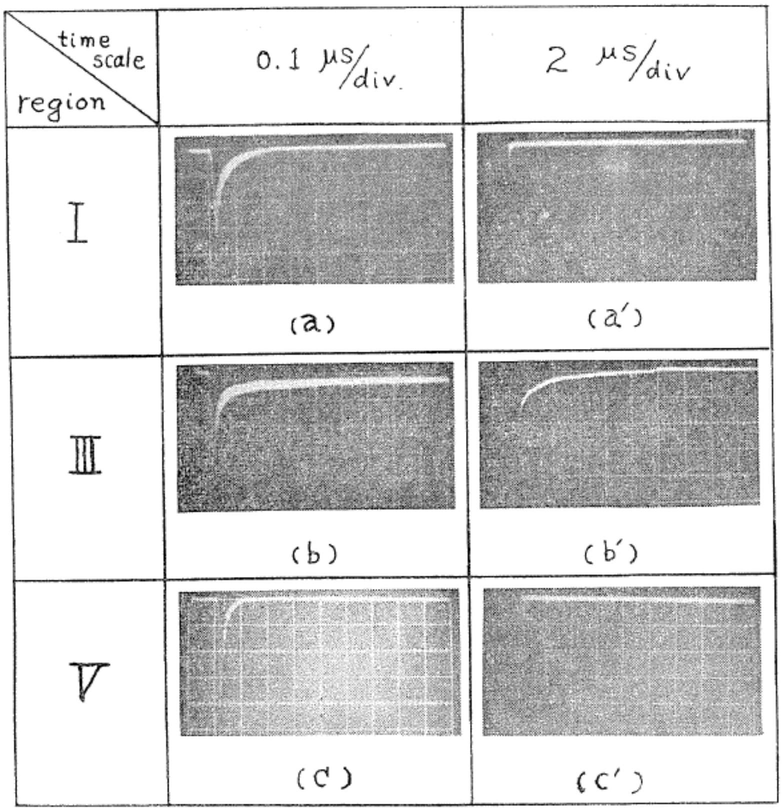


FIG. 9. Examples of corona pulse in each region given in Fig. 8.

(Region V): The time duration of pulse is always below 1 μs again and most often about 0.1 μs as shown in Fig. 9 c.

(Region II and IV): In these regions, there exists at the same time two kinds of pulses observed in both regions neibouring these boundary regions.

5. Visual Observation

Fig. 10 shows microphotographs with a photofilm, Kodak Tri *X* Pan which was exposed to the corona for 10^4–10^6 pulses.

The visual aspect of negative corona under the presence of insulating film in the region I is similar to that of general Trichel pulse as shown in Fig. 10 a and b. In Fig. 10 a, a positive column extends about 1 mm into the gap from the point though its boundary is not so clear. For the exposure of 10^7 pulses, it is likely to extend about 1.2 mm into the gap, while Loeb[2] reported on the positive column extending roughly 1.5 mm with 0.18 mm radius point. From comparing this aspect with Fig. 8 a, it is seen that the critical gap length

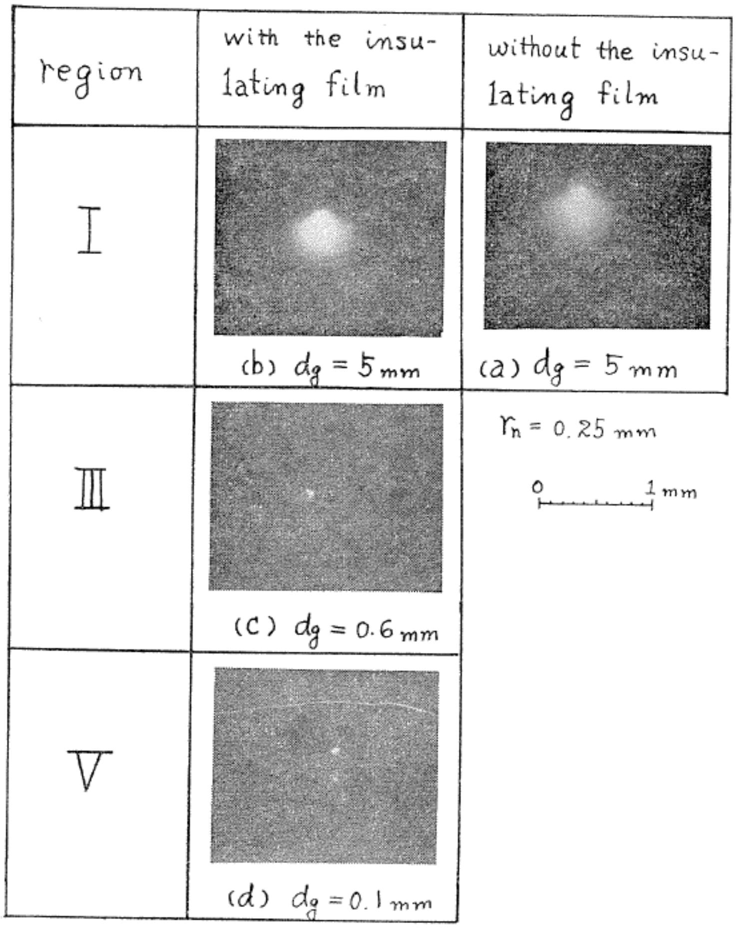


FIG. 10. Visual forms of corona discharge in each region given in Fig. 8.

between the region I and II corresponds to the distance that the top of the positive column just reachs on the surface of insulating film. Then, it may be suggested that an appearence of the corona pulse with a long plateau has a close relation to the fact that some portion of negative space charge, which plays a self-quenching action of discharge, is formed directly on the insulating film. In the region III, where any observed pulse has a long plateau, since the pulse repitition rate is very small, no corona is visible to the naked eye except a faint spot near point. A photograph obtained with a long exposure time, however, indicates a filamentary discharge extending into the gap (See Fig. 10 c). The transition of this visual aspect from region I to region III appears a similar to the transition from general pulsive corona (Trichel pulse) to non pulsive corona[5]. Finally, in the region V having very short pulse duration, a flare fills the gap and extends traversely along the film surface (Fig. 10 d). The lower image observed photo *d* in the figure is due to a reflection from the clean surface of the film.

6. Variations with Radius of Point

In the Trichel pulse corona in the absence of film, a positive column extends further when the radius of point is increased, because of the larger expanded high field region with it. Then, if the critical gap-length between the region I and II is related to the distance across which the positive column lies, it is expected that the larger the radius of the point electrode, the larger the critical gap-length dgc 1. Experimental results show that this relation is qualitatively verified as shown in Fig. 8 a, b and c.

7. Variations with Electrical Properties of Insulating Film

Up to the previous section, we illustrated only results with Sample No. 1 which has a lowest resistivity among specimens cited in Table 1. We now describe the effect of electrical properties of insulating film on the wave form of corona pulse. The critical gap-length dgc 1 defined from the pulse observed at corona starting voltage is almost independent of the kinds of insulator as shown in Table 1. At a voltage above corona inception, however, the division of regions in the $V-dg$ plane as in Fig. 8 is slightly dependent on the kind of insulator. In other words, it may be suggested that whether or not the pulse has the plateau is determined by the distortion of negative space charge near the point while the duration of the plateau is determined by the characteristics of space charge, e.g. its decay speed depending on the difference of insulating film.

8. Discussion

8.1) On the condition of appearence of the pulse having a long plateau

Previously, it was pointed out that the critical gap-length dgc 1 is nearly the distance over which a positive column extends. Moreover, it is now found that the dgc 1 agrees with the gap-length below which, in the absence of the film, spark breakdown occurs without corona discharge; 1.5 mm gap with 0.25 mm radius point and 2.5 mm gap with 0.5 mm radius point (See Fig. 8 a and b).

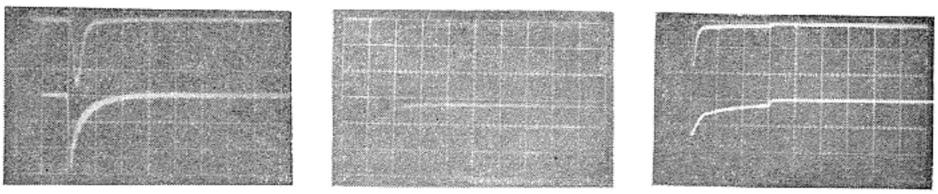
It is suggested from these facts that at a gap-length below dgc 1, the first electron avalanche reaches near the surface of film and produces negative space charge directly on the film.

8.2) On the nature of plateau in the pulse

The plateaus in the different conditions have been observed by some others and analyses for its mechanism have been reported. For instance, K. Honda *et al.*[8) 9)] found that in the bigining of the point corona discharge in air, there appears the pulses having a long plateau, and they pointed out that the plateau is formed by the diffusion current due to the sweep of negative ion space charge. Also, in an ozonizer type discharge, the pulse with similar shape was observed and it was reported that the initial spike in corona pulse is due to the electron current, while the plateau the ion current and amounts of electric charge involved in both parts is nearly the same[10)]. In our case, however, the charge Q_1 in the initial spike is not equal to the charge Q_2 in the plateau, but is smaller than Q_2. This fact suggests that the plateau in our case is caused by an other mechanism. To examine whether the plateau is simply due to the movement of ions after the ionization is choked off, the photon pulse emitted from corona was observed by a photomultiplier 7696. In the region I, the time duration of observed photon pulse is below 0.1 μs, while, in the region III, the photon pulse has also a plateau whose time duration is nearly the same with that of electrical pulse, as shown in Fig. 11 b and c. Since the detected photon pulse is principally due to excitation accompanied with ionization, it is clear that the formation of plateau is based on a self-sustained discharge continued during its period, but not a simple action such as the sweep of ions. Even in usual discharge space without the insulating film, it has been reported that there appears the pulse having a plateau at a voltage a little below the transition voltage from pulsive corona to non-pulsive (pulseless) one. On this kind of plateau, H. Enjoji[6)] has reported that the transition current just before pulseless corona is of 110–150 μA and that just after it is of 120–160 μA. In our case, the current magnitude at the end of the plateau (I_τ) was about 100 μA and almost independent of gap-length, radius of point and kind of film inserted. This value of I_τ is nearly equal to the transition current as described above. From these facts, it may be suggested that the plateau in each pulse is based on a similar mechanism to that in pulseless negative point corona.

9. Conclusion

Negative point corona gives regular Trichel pulses on the base of formation



(a) Region I, $R_a=R_p=100\ \Omega$ time scale; 0.1 μs/div. (b) Region II, $R_a=R_p=100\ \Omega$ time scale; 0.1 μs/div. (c) Region III, $R_a=R_p=100\ \Omega$, timescale; 2 μs/div.

FIG. 11. Photon pulses (upper) and electrical pulses (lower).

and decay of negative space charge near the point. In this report, the discharge forms were studied in such discharge space involving an insulating film which makes disturbance of the negative space charge. The experimental results mentioned above have to be considered in the evaluation of the results of corona resistance tests.

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