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論　文

Effect of Dielectric Enclosure on Point-to-Plane Corona in Air

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This paper is aimed at investigating the effect of a cylindrical dielectric (glass) enclosure on the characteristics of corona discharges in a point-to-plane gap positioned in air along the axis of the enclosure. Experiments have been carried-out with a positive dc voltage applied to the gap for different values of point radius, point-to-plane spacing and enclosure diameter. The corona inception-voltage and current-voltage characteristics were measured in presence and absence of the glass enclosure. With dc voltages above the inception value, a charge may accumulate on the enclosure surface with a subsequent effect on the discharge characteristics. This is in addition to the effect of the enclosure on the geometric field in the gap spacing. All measurements are discussed in the light of gas-discharge physics

1. Introduction

Considerable research has been conducted to ascertain the influence of a multitude of factors on the dielectric strength of gas-insulated systems, which incorporate solid insulating spaces. The effect of insulating spacers is considered to modify the electric field distribution, based on permittivity and geometrical consideration. The influence of intrinsic properties of the insulating spacers other than permittivity on the gas breakdown has not yet been reported in the literature. [1)]

In the field of high-power pulse technology, current pulses of very fast risetimes are frequently needed. This requires transfer switches of extremely low inductance between the energy source and the load. One type of these switches is a gas spark gap. The inductance of the gap switch can be reduced by placing a dielectric plate on the switch, but the effect of the dielectric plate on the gap breakdown is still poorly understood. [2)]

Insulating plates used as shields in HV equipment are known to affect the electric strength of their adjacent spark gaps. The effect is not only due to the modification of the electric field based on permittivity but also to the electric charge accumulated on the plates. The latter is produced by the adjacent spark gaps. The influence of the accumulated charge on the breakdown probability of the spark gaps is not fully investigated. [3)]

Recently, the effect of a dielectric plate on characteristics of the discharges in air from a point electrode was investigated experimentally.[4)] Experiments have been carried out with either 250/2,500 μs switching impulse, or dc voltage applied to the point electrode in the presence of a plexiglass dielectric plate. When a positive impulse is applied to the gap, the first corona (at the tip of the point electrode) is onset-streamer corona, which irradiates the dielectric plate.[4)] On the other hand, when a negative impulse is applied to the gap, the first corona is negative-feather corona, which irradiates also the dielectric plate.[4)] It has been realized[5)] that dielectrics behave like metallic surfaces and emit electrons in atmospheric air when subjected to UV irradiations. This is true whatever the irradiations are emitted from positive or negative impulse coronas. This is why the dielectric plate was charged positively irrespective of the polarity of the applied impulse voltage. The breakdown probability was measured for different crest voltages.[4)] The spatial distribution of the accumulated charge was measured for positive and negative impulse voltages. With dc applied voltages, the charge accumulated on the dielectric plate had the same polarity as the corona ions migrating from the point electrode. The repetition rate and the charge content of the Trichel pulse corona were measured for points stressed by negative dc voltage. Also the repetition rate and the charge content were measured for positive onset streamer pulses. All measurements were discussed[4)] in the light of gas-discharge physics.

A theoretical analysis was aimed[6)] at assessing the onset voltage of the dc corona from a point electrode as influenced by a nearby dielectric plate as well as the charging of the plate by the corona space charge. The electric charge in the vicinity of the point electrode was calculated using the charge simulation technique where the gap electrodes were stimulate[6)] by discrete charges and the dielectric plate by the area charges. The potential and the field in the vicinity of the stressed electrode as well as the maximum surface charge on the dielectric plate were determined by applying suitable boundary conditions during voltage application. The distribution of the surface charge on the dielectric plate was measured by means of an electrometer with a specially designed electrostatic probe. The calculated onset voltages and surface charge distributions were compared[6)] with those measured experimentally.

Key words: corona discharge, wall effect, corona onset voltage, gas discharge, dielectric surface

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For investigating gas discharge characteristics as influenced by the gas pressure, test spark gaps were supported[7] in dielectric enclosures, usually cylindrical in shape, the gap axis extends along that of the enclosure. The accumulated charge on the enclosure walls changes the field along the gap axis, where discharge activity takes place. This is in addition to the change of the geometric field by the presence of the dielectric enclosure. All of these effects will influence the discharge characteristics of the test gap.

Modern studies on electrostatic discharges have been prompted by interest in the prevention of ignition hazards and in damage/interference avoidance during high-performance microelectronic operations. The subject has been documented and reviewed.[8] With the advent and increased use of plastics, synthetic materials and other high polymer materials in both industry and the daily lives of people, recent attention has been increasingly directed to the behavior of discharges from charged insulating surfaces. When a conducting object is brought near to the charged insulating surface, a micro-spark is triggered if the separation between the object and the surface is short enough and if the charge level on the surface is sufficiently high. Subsequently, a current pulse flows in the object circuit and a brush discharge develops on the surface. Such events were carefully studied with a thin dielectric sheet backed by a metal plane and ground object.[9] Point-to-plane experiments[9, 10] showed that, in a source-driven steady dc discharge, corona activity tends to be impeded by the presence of surface charges on a dielectric sheet covering the ground plane (non-coronating electrode). A fully developed theory for such activities should be consulted[11] for a proper interpretation of the charge accumulated on the dielectric sheet.

The present work is aimed at the experimental study of the interaction between the processes taking place in the stressed gas volume of a positively-stressed point-to-plane gap and those occurring at the enclosure walls. This reflects itself on a change of the corona onset voltage and current voltage characteristics with the presence of the dielectric enclosure. Such change will be investigated in the present paper. First of all, charging of the dielectric surfaces will be briefly reviewed. Then the experimental setup is described and the obtained results are discussed in the light of gas-discharge physics.

2. Charging of Dielectric Surfaces

Different mechanisms of dielectric charging have been suggested based on the source of charge. Charging of a dielectric surface is caused by:

1. Surface conduction which results from field dependence of surface conductivity of the dielectric.[12]

2. Bulk conduction which results from nonlinear or non-uniform or field dependence of bulk conductivity of the dielectric.[13]

3. Field emission of electrons at the sharp edges on nearby electrodes energized by negative dc voltages. the negative charge carriers migrate in the gas along electric field lines. Positive charges accumulate at the places with field vectors pointing into the dielectric surface, negative charges opposite. The charge density varies with the field magnitude. [12, 14-17]

4. Partial discharges in the neighborhood of the dielectric surface.[18, 19] The ions produced migate in the gas along the field lines toward the surface.

5. Homocharge and heterocharge distributions on spacer surfaces. In the first positive charges accumulate near the positive electrode and negative charges near negative electrode of post spacers. In the latter, charges of opposite polarity accumulate in the vicinity of each electrode of post spacers with metal inserts. The transport of charge carriers in the gas in the cause of these types of charging depending on the triple-junction profile of the spacers.[12, 14, 17]

6. Field emission of electrons from the dielectric surface due to UV irradiation where the dielectrics behave like metallic surfaces.[5]

The charging process by transport of charge carriers in the gas along the direction of the electric field takes place very rapidly. On the contrary, charging due to surface conduction occurs over a time period of hours rather than seconds[1,12] as in the case of charge carriers produced by field emission and transport in the gas. Charging due to bulk conduction also takes along time. The final charge accumulation is determined mainly by the transport of charge carriers in the gas and not by the bulk or surface electric conductivity of the dielectric. This is supported by the fact that the surface or volume conductivity of the dielectric is very small, in particular for the relatively low electric field values in the dielectric.16) Transport of charge in the gas depends on the initial external field distribution.

3. Experimental Setup and Technique

The investigated gap in this work was a conical point with round tip against a plate grounded through a micro-ammeter as shown in Fig.1. The point-to-plane gap spacing d was variable in the range 2 to 8 cm. Different points were attempted with tip radius r_t of 0.45 mm, 0.5125 mm and 0.645 mm. The radius r of the point shank was constant at 2.5 mm. The length ℓ in Fig.1 was 10 mm. The micro-ammeter was used for measuring the corona current and assessing the corona onset voltage which corresponds to a zero-current reading.

To investigate the effect of dielectric enclosure, a glass tube of inner diameter D, thickness t and height H was positioned coaxially with the gap axis. Different tubes were used with diameter D of 0.08, 0.10 and 0.16 m. The relative permitivity and conductivity of the glass tube were 6.3 and 10^{-12} $\Omega^{-1}m^{-1}$ respectively. The height H and thickness t were constant at 28 cm and 0.5 cm, respectively. The gap was stressed by dc voltage of positive polarity. To produce the positive dc voltage, a Greinacher doubler circuit of 280 kV, 5 mA was built as shown in Fig.2. The applied voltage was measured through a resistive voltage divider as shown in Fig.2.

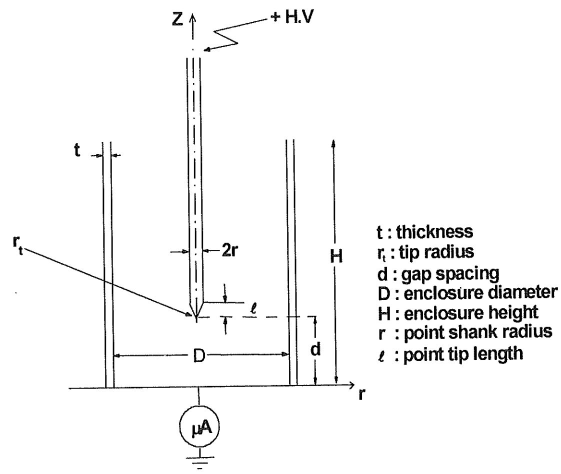

Fig.1 Experimental setup showing the point-to-plane gap in a coaxial enclosure.

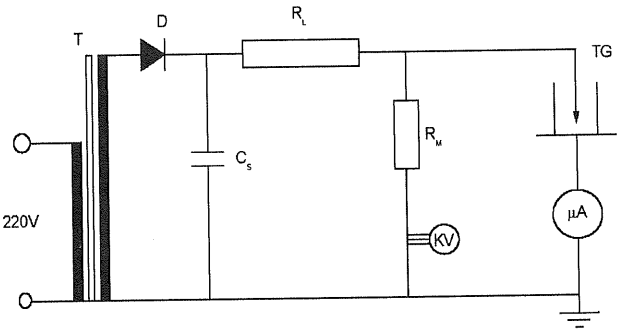

Fig. 2 High voltage dc supply connected to the test gap. D: Selenium rectifier, 140 kV-PIV, 5 mA, C_S: dc capacitor, 140 kV, 6 nF, R_M: Measuring resistor, 140 kV, 280 MΩ, R_L: Protective resistor, 140 kV, 10 MΩ, 60 W, TG: Test gap, T: HV transformer, 220 V/100kV.

A charge may accumulate on the glass tube following the application of dc voltages to the test gap. To discharge the dielectric cylinder between tests, an AC voltage was applied to the test gap to produce bipolar ions so that the surface could be completely neutralized between tests.

4. Results and Discussion

At a critical value of positive dc voltage applied to the gap, an abrupt current increase signals the development of an ionization form that produces onset-streamers. The ionization is produced by growing avalanches and is restricted to a very thin layer around the tip of the point electrode called "ionization zone". The electrons of the avalanches get absorbed by the point leaving behind positive ions. These ions increase in number to the limit that reduces the field and suppresses the development of further avalanches. Another onset streamer can start only after the positive ions have sufficiently moved out of the ionization-zone. This explains the pulsed character of the onset streamers. The inception voltage V_o is the critical value of the applied positive dc voltage at which the onset streamers become self-recurring (repetitive). This is determined by the electric field in the vicinity of the stressed point. Such field is influenced by the charges on the inner and outer surfaces of the enclosure.

The inception voltage of onset streamers increases with the gap spacing in presence or absence of the dielectric (glass) enclosure, Figs.3 and 4. Moreover, the inception voltage increases with the increase of the tip radius of the point, Figs.3 and 4. This is simply explained by the decrease of the field in the ionization zone surrounding the point following the increase of the point radius. The increase of gap spacing decreases the field along the gap axis, and hence decreases the field in the ionization zone with a subsequent increase of the inception voltage, as shown in Figs.3 and 4.

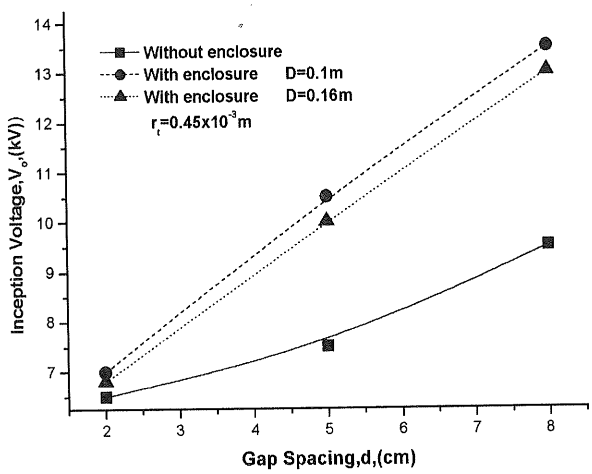

Fig.3 Inception voltage V_0 versus the gap spacing d with and without enclosure ($r_t = 0.45 \times 10^{-3}$ m).

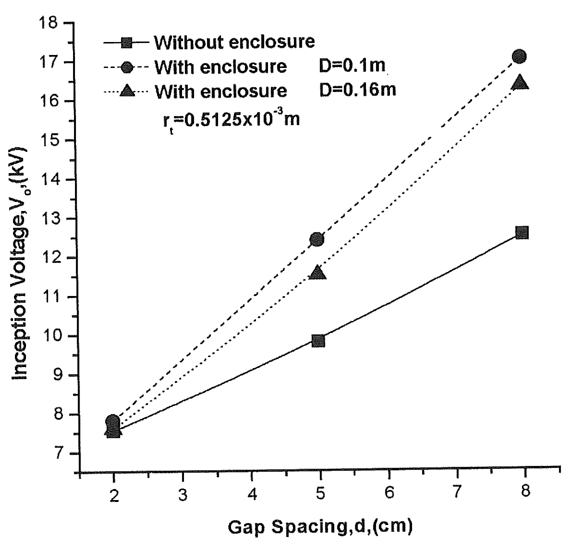

Fig. 4 Inception voltage V_0 versus the gap spacing d with and without enclosure ($r_t = 0.5125 \times 10^{-3}$ m)

The presence of the dielectric enclosure changes the geometric field in the gap due to the surface polarization charges. For positive dc voltage applied to the point, the polarization charge on the inner surface of the enclosure assumes negative polarity.[6, 20] The amount of this polarization charge is directly related to the applied dc field. Therefore, the longer the gap spacing, the smaller is the amount of negative polarization charge. On the other hand, the polarization charge on the enclosure outer surface is positive. It is worthy to mention that the polarization charge appears only when the point is stressed by a dc voltage (not exceeding the inception value V_o) and the polarity of it on the inner surface of the enclosure is opposite to that of the stressed point.

The distribution of the negative polarization charges can be simulated by a set of ring charges on the inner surface of the enclosure, Fig.1. For a ring charge having a charge Q_r, radius r_r (=D/2) and height Z_r above the ground plane, the field component E_Z (along the Z-axis, Fig.1) at the tip of the stressed point is calculated as:[21)]

$$E_Z = \frac{-Q_r}{4\pi\varepsilon_o} \frac{(Z_r - Z_t)}{[r_r^{\,2} + (Z_r - Z_t)^2]^{3/2}} \qquad (1)$$

where Z_t (=d) is the z-coordinate of the tip of the point and ε_o is the permitivity of free space. The value of E_Z assumes positive value as long as $Z_r > Z_t$, provided that Q_r is negative.

As the gap spacing d (=Z_t) is much smaller than the height H of the enclosure, the number of ring charges having z-coordinate Z_r greater than Z_t is larger than that of the rings with $Z_r < Z_t$. Therefore, the resultant value of E_z at the point tip due to all the polarization charges over the inner surface of the enclosure assumes positive value, i.e. opposite to the field component due to the applied dc voltage which extends axially downwards.

The contribution of the positive polarization charges on the outer surface is smaller in magnitude and opposite in polarity with respect to that on the inner surface. This is simply explained by the larger radius of the rings (D/2 + t) on the outer surface, where t is the thickness of the enclosure, as shown in Fig.1, and depicted by Eq. (1).

Therefore, the net effect of the polarization charges on the inner and outer surfaces of the enclosure is to produce at the point tip a field component opposite to the axial field produced by the applied dc voltage. That component increases with the increase of the gap spacing. Subsequently, the presence of the dielectric enclosure (with height H much larger than the gap spacing d) decreases the field inside the ionization-zone surrounding the stressed point. This is why the inception voltage assumes higher values in the presence of the enclosure in comparison with those in free space (air), i.e., without enclosure, as shown in Figs.3 and 4. The smaller the diameter of the enclosure and the longer the gap spacing, the larger is the effect of enclosure on increasing the inception voltage for the same tip radius and gap spacing, as shown in Fig.5. The smaller the tip radius of the point, the higher is the field in its vicinity and the smaller is the effect of the enclosure in decreasing the field inside the ionization zone surrounding the point and in increasing the inception voltage V_o of the onset streamers, as shown in Fig.5. This figure shows how the rate of increase of V_o due to the enclosure (with polarization charges on its inner and outer surfaces) increases with the gap spacing for different point radii and enclosure diameters. The rate of increase of V_o is expressed as equal to

$[V_{o \text{ with enclosure}} / V_{o \text{ without enclosure}}]$

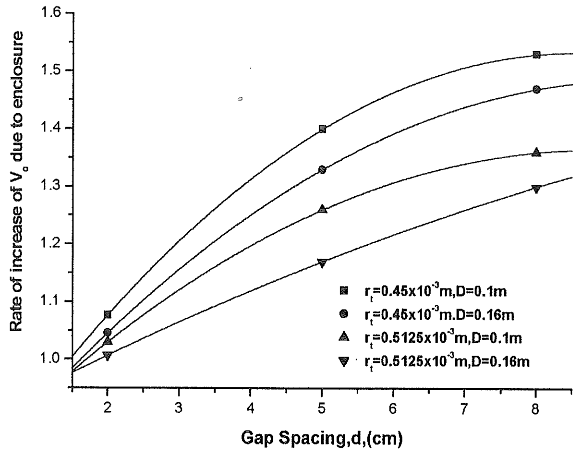

Fig. 5 Rate of increase of the inception voltage V_0 versus the gap spacing d for different values of point radius r_t and enclosure diameter D.

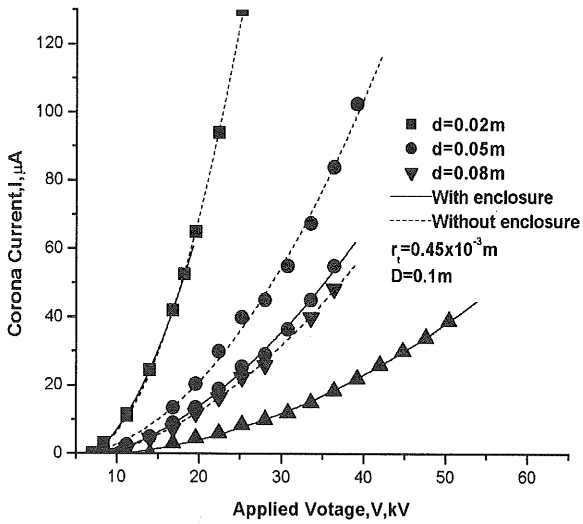

Fig. 6 Effect of enclosure on the corona current-voltage (I-V) characteristics for different values of gap spacing d. Tip radius r_t of the point = 0.45×10^{-3} m and enclosure diameter D = 0.1 m

Further increase of the applied positive dc voltage results in increasing the repetition rate of the onset streamers. Eventually, they merge in time and space to form a glow discharge. Therefore, the higher the applied voltage the higher is the time-averaged corona current with and without enclosure surrounding the gap, as shown in Figs. 6–9.

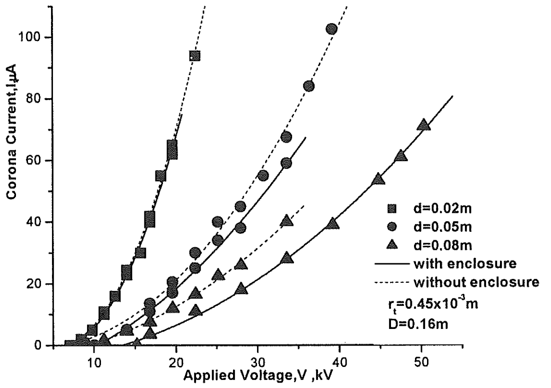

Fig. 7 Effect of enclosure on the corona current-voltage (I-V) characteristics for different values of gap spacing d. Tip radius r_t of the point = 0.45×10^{-3} m and enclosure diameter D = 0.16 m.

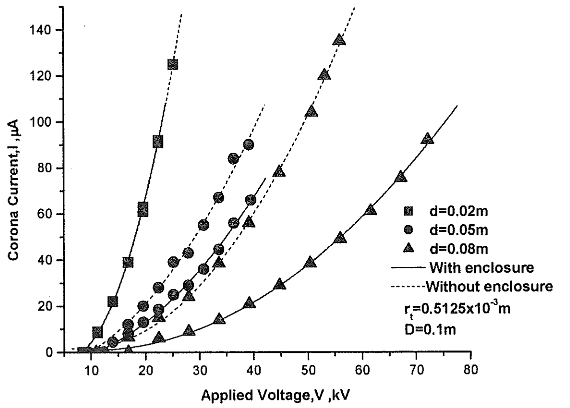

Fig. 8 Effect of enclosure on the corona current-voltage (I–V) characteristics for different values of gap spacing d. Tip radius r_t of the point = 0.5125×10^{-3} m and enclosure diameter D = 0.1 m.

The presence of the glass enclosure bounds the discharge space and results in a decrease of the corona current. The smaller the diameter of the tube, the more is the decrease of the corona current for the same applied voltage, same tip radius and same gap spacing, as shown in Figs.6–9. As the applied voltage is steady positive dc, there is ample time for the positive ions produced by onset-streamers or glow discharge to travel to the glass enclosure to charge it positively, thus counterbalancing the polarization charge. Therefore, the positive ionic charge is accumulated on the lower portion more than on the upper portion of the glass enclosure with a subsequent decrease of the field inside the ionization-zone and diminishment of the discharge activity in the zone.[4,6] Subsequently the corona current decreases with the presence of the dielectric enclosure for the same applied voltage, tip radius and gap spacing. The corona current increases with the applied voltage in the presence of the glass enclosure, the same as the case without enclosure, i.e. in a free discharge space. This is simply explained by the increase of the density of the positive ions drifting along the field lines from the point to the ground plane. This is in addition to the increase of the geometric field driving the ions in their way to the ground plane.

The larger the gap spacing, the larger the volume through which the discharge develops. Subsequently, the more the ions received by the glass enclosure, the higher the ionic charge accumulated on the lower portion of the glass tube and the weaker is the field inside the ionization zone. This is why the effect of the glass tube on decreasing the discharge activity becomes more pronounced with the increase of the gap spacing for the same applied voltage, as shown in Figs.6–9. This explains why the observed decrease of the corona current due to the presence of the dielectric enclosure becomes more pronounced with the increase of the gap spacing, as shown in Figs.6–9.

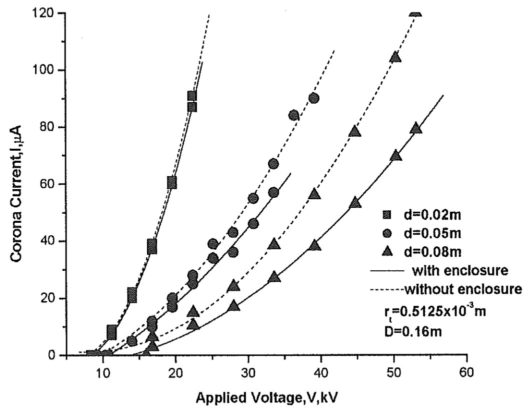

Fig. 9 Effect of enclosure on the corona current-voltage (I–V) characteristics for different values of gap spacing d. Tip radius r_t of the point = 0.5125×10^{-3} m and enclosure diameter D = 0.16 m.

5. Conclusions

On the basis of the present analysis of the interaction between the processes taking place at the stressed point electrode and those occurring at the dielectric enclosure, one may draw the following conclusions:

(1) The corona inception voltage increases with the increase of the point radius for the same gap spacing. It increases also with the increase of the gap spacing for the same point radius.

(2) The corona inception voltage increases due to the presence of the dielectric enclosure for the same radius and gap spacing. The increase is more pronounced with the decrease in the enclosure diameter and the increase of the gap spacing.

(3) The corona current with and without enclosure increases the applied voltage whatever the value of the point radius, the gap spacing and enclosure diameter.

(4) The corona current decreases due to the presence of the enclosure for the same applied voltage. The decrease is more significant with the increase of the gap spacing and the decrease of the enclosure diameter.

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References

1) T. S. Sudarshan and R.A. Dougal: IEEE Trans. Electr. Insul., **21** (1986) 727
2) S. T. Pai and J. P. Marton: J. Appl. Phys., **53** (1982) 8583
3) Z. Flisowski and W. Koltunowicz: Fifth *International Symposium High Voltage Engineering*, p. 14.20, Braunschweig (1987)
4) M. Abdel-Salam, P. Weiss and B. Leiske: IEEE Trans. Electr. Insul., **27** (1992) 309
5) Y. Gosho and M. Saeki: *Fifth International Symposium High Voltage Engineering*, p. 23.24, Braunschweig (1987)
6) M. Abdel-Salam and P. Weiss: IEEE Trans. Electr. Insul., **27** (1992) 320
7) B. Messwandler: *High-Voltage Kits for Testing, Construction Manual*, Bamberg (1986)
8) W.D. Greason: E*lectrostatic Discharge in Electronics*, (Somerset, UK: research studies), chapter 2 (1992)
9) T.S. Lee and J. Gasal: IEEE Trans. Ind., **33** (1997) 692
10) S. Kulkarni, R. Van brunt and V. Lakdawla: *Proceedings of Conference on Electric Insulation and Some Dielectric Phenomena* (Pocono Manor, PA 28–31 October), p. 267(1990)
11) M. Abdel-Salam, H Singer and A. Ahmed: J. Phys. D: Appl. Phys., **34** (2001) 1219.
12) K. Nakanashi., A.Toshioka, Y. Araha and Y. Shibuya: IEEE Trans. Power Appar. Syst., **102**(1983) 3919.
13) C.W. Mangelsdorf and C.M. Cooke: *Proceeding IEEE International Symposium Electrical Insulation*, 146, Boston, (1980)
14) H. Fujinami, M. Yshima and T. Takuma: *Fifth International Symposiom High Voltage Engineering*, p. 13.02, Braunschweig (1987).
15) S. Sato, W.S. Zangel.and A.Knecht: IEEE Trans. Electr. Insul., **22**, (1987) 333
16) H. Ootera and K. Nakanishi: IEEE Trans. Power Delivery, **3** (1988) 165
17) A. Knecht: *Gaseous Dielectrics III Proceeding*s, Pergamon Press, New York, p.356 (1982)
18) C.M. Cooke: IEEE Trans. Electr. Insul., **17** (1982) 172
19) P. Connolly, O. Farish and R.A. Fourace: *Fourth International Symposium High Voltage Engineering*, p. 45.06, Athens (1983)
20) M. Abdel-Salam, H. Singer and A. Ahmed: J. Phys. D: Appl. Phys., .**33**, (1997) 1017
21) M. Abdel-Salam: *Electric Fields, in High Voltage Engineering – Theory and Practice*, eds. M. Abdel-Salam *et al.*, Marcel Dekker, Inc., New York (2000).