

APPLICATION OF POPKOV'S FORMULA TO CORONA CURRENT IN STREAMER REGION

By

HOSNIA M. ABU-ZEID and M. B. OSMAN

Faculty of Women, Ain Shams University

ABSTRACT

The fitting of Popkov's formula to the corona current data obtained from experimental results in the streamer region has been treated. A reasonable agreement can be obtained only when the empirical constant P has a value which varies with the anode — to — cathode separation.

INTRODUCTION

The exact description of the ionized field in a coaxial cylindrical configuration was first solved by Townsend⁽¹⁾. The following simplified equation⁽²⁾ describes a unipolar ionized field.

$$E \frac{d^2 E}{dr^2} + \frac{3E}{r} \frac{dE}{dr} + \left(\frac{dE}{dr} \right)^2 = 0 \dots\dots\dots (1)$$

where E is the electric field in the presence of space charge.

Applying eq. (1) needed appropriate boundary conditions. The potential difference between the two electrodes is the first boundary condition required, and the second is the electric field at the boundary between the corona layer and the space-charge region. Following an approximate analysis⁽³⁾, it has been assumed that the electric field at the anode surface remains constant at the onset value as the anode voltage is increased and that the net space charge in the corona layer is zero.

Sarma and Janischewsky^(2,4) have done a theoretical analysis of the electric field distribution in the ionization layer of a d.c. Corona discharge under equivalent steady-state condition. They reached several conclusions. The most significant one shows that for the range of corona currents encountered on streamer counter, the change in the field intensity at the surface of the anode from the onset value is negligible. The analysis also indicated that accuracy

of corona loss calculations is not significantly affected if the unipolar space charge is assumed to start at the anode surface itself rather than at the corona layer boundary. In a nondimensional form, the voltage — current relation for the cylindrical configuration is obtained as :

$$\frac{V - V_0}{V_0} \text{Ln} \left(\frac{R}{r_0} \right) = (1 + y)^{1/2} - 1 + \frac{2}{1 + (1 + y)^{1/2}} \quad (2)$$

with $y = \frac{I}{\pi \epsilon k} \left(\frac{R}{E_0 r_0} \right)^2$

- were y = nondimensional current,
- V = voltage applied to anode.
- V_0 = Corona onset voltage.
- r_0 = Radius of anode wire.
- R = Radius of outer cylinder.
- I = Corona current per unit length of anode wire.
- K = Ionic mobility.
- E_0 = Corona onset field at conductor surface (5).
- ϵ = Permittivity of free space.

SOLUTION FOR WIRE—TO—PLANE GEOMETRY

To obtain analytical solutions for complicated configurations needs simplifying assumptions which are not normally needed in the simple cylindrical configurations. For complicated cases such as the line-to-plane geometry Deutsch (6) made an approximate analysis. Popkov (7,8) in his analysis of the cylindrical and the line-to-plane geometry following Deutch's work has introduced certain improvements. He assumed that the line-to-plane configuration can be approximated by an equivalent cylindrical system and obtained the following equation for its voltage — current characteristic,

$$-0.41 p \frac{V - V_0}{V_0} \text{Ln} \left(\frac{2 h_a}{r_0} \right) = (1 + y)^{1/2} - 1 + \frac{2}{1 + (1 + y)^{1/2}} \quad (3)$$

$$\text{where } y = \frac{P I}{2 \pi \epsilon k} \left(\frac{h_a}{E_0 r_0} \right) \dots\dots\dots (4)$$

and h_a = height of anode above cathode.

P = Popkov's empirical constant.

The nonuniformity distribution of the current along the plane cathode is taken into consideration by introducing the empirical constant P .

The applicability of Popkov's formulas to practical systems has been discussed by Simpson and Morse (9). For corona in a cylindrical configuration they observed good agreement between eq. 2 and the experiment.

Accurate measurements were also made of corona current for line-to-plane configuration and the results were compared with Popkov's formula in eq. (3). Simpson (10) observed reasonable agreement between theory and experiment only when the empirical constant P was increased from 1.65 to about 5.

RESULTS

In the present work the corona currents measured by a streamer wire-plane detector ($2r_0 = 0.29$ mm. and $L_c = 75$ mm.) for different heights above the cathode are compared with the theoretical results computed by using eq. (3) for various values of P . The values of P that give negligible difference between the computed results and the experimental ones are given in table (1). Table (1) shows that Popkov's empirical constant P varies with the counter parameter h_a .

TABLE 1
Variation of the empirical constant P
with the counter parameter h_a

h_a mm.	h_a/r_0	P
5	17.2	2.8
7	24.1	3.6
9	31.03	4.5

To illustrate the above mentioned observation more clearly fig. (1) shows the calculated curves by using eq. (2), and using the selected values of the empirical constant P cited in table (1), for h_a values of 5, 7 and 9 mm. On the same curves are represented the experimental results in circles. It might be seen from such curves that there is a good agreement between the experimental results and the computed values. It is evident that the values of P depends on the corona current intensity. However it has to be noticed here that in all the previous results the load resistance R ($10\text{ M}\Omega$) was between anode and E.H.V., the cathode is almost directly earthed. Actually this structure is different from the configuration taken by another author (11).

ACKNOWLEDGEMENT

The authors would like to express their thanks and gratitude to Prof. Dr. M. Mahrous, Head of the Physics Department, Girls College, Ain Shams University for his interest and supplying the necessary facilities throughout this experimental work.

The authors also express their thanks to Prof. Dr. H.M. Abu-Zeid, Atomic Energy Establishment for his interest and useful advices.

REFERENCES

1. J.S. Townsend, Phil. Mag., Vol. 28, 83 (1914).
2. M.P. Sarma, «Analysis of Corona losses for d.c. transmission line configurations», Ph.D. dissertation, University of Toronto, Toronto, Ont., Canada, (1968).
3. N.A. Kapzow «Electriche Vorgange in Gasen and in Vacuum» Berlin VEB Deutscher Verlag der Wissenhaften PP. 488 (1955).
4. M.P. Sarma, and Janiscewskyj, Proc. IEEE trans. Power Apparatus and systems, Vol. PAS 88, No. 5, 718 (1969).
5. Abu-Zeid, Hosnia, Ph. D. Thesis, Ain Shams Univ. Girls College (1971).
6. W. Deutsch, Ann. Physik, 5, 589 (1933).
7. V.I. Popkov, Elektrichestvo, No. 1, 33 (1949) NRC Tech. Transl. TT — 1093.
8. V.I. Popkov, «Some special Features of Corona on High Voltage d.c. transmission lines» in Gas Discharge and the Electricity supply Industry. London ; Butterworth, 1962.

9. J.H. Simpson and A.R. Monse. Bull. Radio. Elec. Eng. Div. Natl — Res. Council of Canada), 14, 18 (1964).
10. J.H. Simpson, «Theoretical and experimental studies of Corona loss from D.C. lines» Presented at the Canada Res. Meeting, Montreal, P.Q. Canada, March 17—18 (1966).
11. Gad E. A., Ph. D. Thesis, Ain Shams Univ. Girls College, (1972).

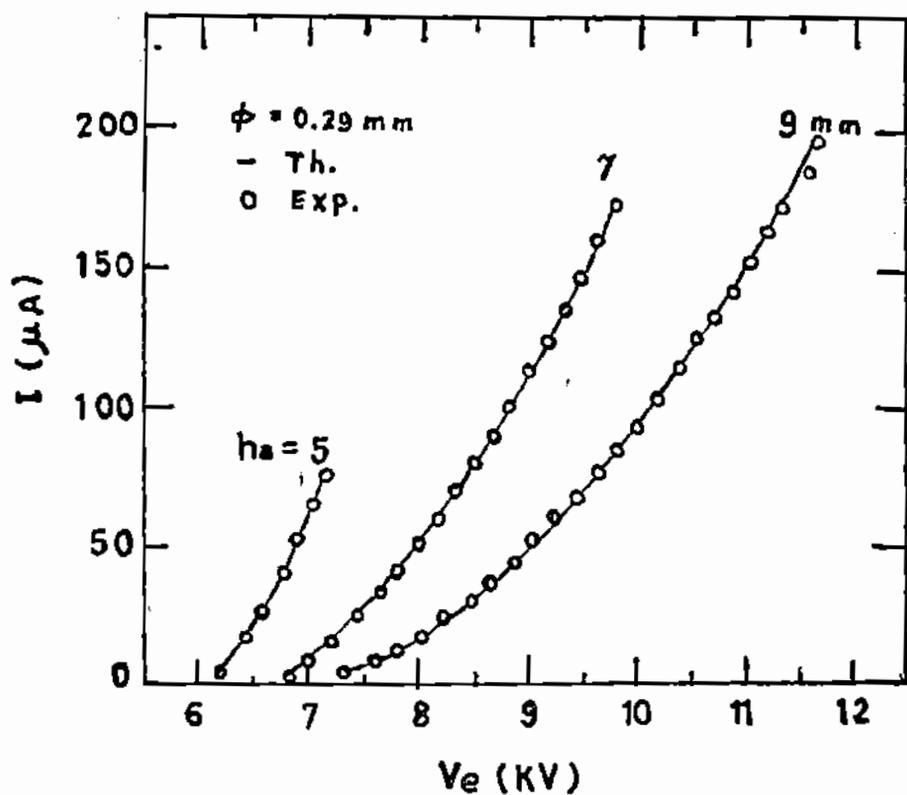


Fig. 1 — I V S V_e computed from pokov's empirical formulae for various values of h_a (5, 7, 9 mm) with the load resistance $R = (10 \text{ M } \Omega)$ connecting anode to E.H.T.