CURRENT - VOLTAGE CHARACTERISTIC OF A CORONA
DISCHARGE IN A DISPERSIVE MEDIUM

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The current-voltage (I-V) characteristic for a corona discharge in a dispersive medium is derived on the basis of the Townsend assumptions for a coaxial cylindrical system. The expressions found can be used to find the discharge current in a dispersive medium and the condition for total discharge cutoff over a wide range of concentrations of the dispersive phase. The calculated results are found to be in satisfactory agreement with experiment.

It has been established theoretically and experimentally that the introduction of a dispersive phase into a corona gap during its charging changes the structure of the electric field of this gap and reduces the corona current \[1-3\]. So-called discharge damping also occurs. Experience shows that the discharge current, in, e.g., an electric separator, often vanishes, causing a sharp reduction of the efficiency of the apparatus \[4, 5\].

Discharge damping was first described quantitatively by Pauthenier and Moreau-Hanot \[1\] for the case of tubular electric separators. The Poisson equation for a two-phase medium was solved, yielding the relative decrease in the discharge current:

\[
\frac{i}{i_0} = 1 - \frac{SpR}{3},
\]

where \(i_0\) and \(i\) are the discharge (or corona) currents in pure air and in the presence of the dispersive phase, respectively; \(p = 1 + 2(\varepsilon_{\Gamma} - 1)/(\varepsilon_{\Gamma} + 2)\) is a parameter which depends on the dielectric constant \(\varepsilon_{\Gamma}\) of the particle material; \(R\) is the radius of the peripheral electrode - the tube; and \(S = 4\pi\Sigma a_j^2n_j\) is the total surface area per unit volume of the dispersive-phase particles (the "elementary surface area") for a dispersive phase containing \(j\) fractions; the particles of each fraction have a radius \(a_j\) and a concentration \(n_j\).

Equation (1) is relatively inaccurate, however, and is of restricted usefulness. It gives the relative rather than the absolute discharge current, and it holds only for an intense corona at low particle concentrations corresponding to \(SpR < 1\). In addition, it does not take into account either the applied voltage or the corona-ignition voltage.

We have obtained an expression for the I-V characteristic of a corona discharge in a dispersive medium which is valid even at high concentrations. High particle concentrations corresponding to \(SpR > 1\) are observed, e.g., upon the shaking of an electric separator. An equation is described below which describes the discharge damping, and an experimental check of this equation is reported.

The Townsend assumptions (negligible field distortion due to the ionic space charge and the constant space-charged density along force lines \[6\]) are used in deriving the equation for the I-V characteristic. The medium is assumed isotropic, since the volume of the dispersive phase is much less than that of the dispersive medium and the dielectric constants are of the same order of magnitude. Under these conditions the Poisson equation can be written

\[
\text{div } E = \frac{1}{\varepsilon_0} (\varepsilon_i + \rho_i),
\]

where \(\rho_i\) is the ionic space-charge density, and \(\rho_{\sigma} = Sp\varepsilon_0\sigma = \varepsilon_0\sigma\varepsilon_0\) is the space-charge density of the dispersive phase.
In cylindrical coordinates, Eq. (2a) becomes
\[ \frac{1}{r} \frac{d(rE)}{dr} = \frac{\varepsilon_i}{\varepsilon_0} + \sigma E. \] (2b)

We denote by \( E_0 \), the electric field intensity at the surface of the coronating electrode \((r = r_0)\) in the presence of the dispersive phase. Then solution of (2b) under the condition \( \rho_1 = \text{const} \) yields
\[ E = E_0 \frac{\rho_1}{r} + \frac{\rho_1}{\varepsilon_0 \varepsilon_r} \left( \frac{\varepsilon_r}{r} - \frac{1}{r} - \varepsilon \right). \] (3)

Integrating (3) from \( r_0 \) to \( R \) and neglecting the terms containing \( r_0 \) in the series expansions, we find an expression for the applied voltage:
\[ U = E_0 \ln \frac{R}{r_0} \left[ 1 + \sum_{n=1}^{\infty} \frac{(zR)^n}{n \cdot n!} \right] + \frac{E_0}{\varepsilon_0} \ln \frac{R}{r_0} \sum_{n=2}^{\infty} \frac{(zR)^{n-2}}{n \cdot n!}. \] (4)

Using the Townsend assumptions, and neglecting the change in the field intensity at the surface of the coronating conductor caused by the charged dispersive phase, we can write
\[ E_{0i} = E_0 = \frac{U_0}{r_0 \ln \frac{R}{r_0}}, \]
\[ E_R = \frac{U}{R \ln \frac{R}{r_0}}, \] (5)

where \( E_0 \) is the electric field intensity at the surface of the coronating conductor at the instant the corona is ignited in pure air, \( U_0 \) is the corona-ignition voltage, and \( E_R \) is the field intensity at the surface of the peripheral electrode.

Using (5) we can write
\[ \varepsilon_i = \frac{i}{2\pi \kappa E_R} = \frac{i}{2\pi \kappa U} \ln \frac{R}{r_0}, \] (5')

where \( \kappa \) is the ion mobility.

Using (5) and (5'), we can convert (4) to
\[ U = U_0 \left[ 1 + \frac{1}{\ln \frac{R}{r_0}} \sum_{n=1}^{\infty} \frac{(zR)^n}{n \cdot n!} \right] + \frac{R^2 \ln \frac{R}{r_0}}{2\pi \kappa \varepsilon_0} \frac{i}{U} \sum_{n=2}^{\infty} \frac{(zR)^{n-2}}{n \cdot n!}. \] (6)