The Investigating and Simulating the Corona Phenomenon in The Power Transmission Lines of Power Networks Using the Finite Element Method

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ABSTRACT:
In this article, the simulation of the physical phenomenon of coaxial corona discharge in air, in DC mode using the finite element method is discussed. Basically, to optimize the production process of ionized gas and any other physical phenomenon, we model and simulate the phenomenon. To simulate this phenomenon, from two cylindrical electrodes, one inside (cathode) and the other outside (anode), the radius of the inner electrode is 100 microns and the distance between the electrodes is 10 cm. A constant voltage of 50 kV is applied to the inner electrode. The outer electrode is considered the ground. Our emphasis is on the formation of charged particles and their behavior in the resulting electric field. In order to avoid the complexity of the problem and save the simulation time, we model in a one-dimensional way and in the results extract the above phenomenon in a two-dimensional way. The gas temperature is 640 K and the air density is considered constant.

KEYWORDS: Corona DC Discharge, Plasma, Power Systems, Finite Element Method, Ionisation.

1. INTRODUCTION

One of the physical phenomena that occurs in contact with electric equipment, especially power transmission lines and high-pressure equipment, such as plasma caused by electric discharge, is corona or halo [1-3]. The electric field near the conductive material can be concentrated enough to ionize the surrounding air. This issue can lead to a partial discharge of electrical energy. Various factors such as voltage, shape and diameter of the conductor, roughness of the conductor surface, dust and water droplets can cause the surface gradient of the conductor, which will eventually cause the formation of corona [4]. If the distance between the conductors is small, corona may cause sparking and short circuit. It is obvious that corona causes the loss of electrical energy and the reduction of electrical efficiency of transmission lines. Corona phenomenon also causes interference in radio waves [5-7].

In 2010, Pekarek et al investigated the effect of magnetic field on the production of ozone from air by negative corona discharge in a cylindrical electrode arrangement. For this purpose, they used a steel needle inside the chamber as the cathode and the outer wall of the cylinder as the anode. The discharge voltage is 12 kV and the discharge current is 0.6 mA. [8]. In 2018, Riba et al did a comparative analysis between corona in ac mode and positive and negative corona in dc mode. At first, air distance was analyzed with practical data. By simulating the finite element, the intensity of the surface electric field is determined [9].

This article deals with simulating the physical phenomenon of coaxial corona discharge in air and in DC mode using the finite element method. Basically, to optimize the production process of ionized gas and any other physical phenomenon, we model and simulate the phenomenon. Two coaxial electrodes are used and the radius of the inner electrode is 100 microns and the distance between the electrodes is 10 cm. A constant voltage of 50 kV is applied to the inner electrode (cathode). The outer electrode (anode) is considered the ground. Our emphasis is on the formation of charged particles and their behavior in the resulting electric field

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in the space between the electrodes. Fig. 1 shows the simulation geometry. To avoid the complexity of the problem, we model one-dimensionally and extract the results in two-dimensionally. The gas temperature is 640 K and the air density is considered constant.

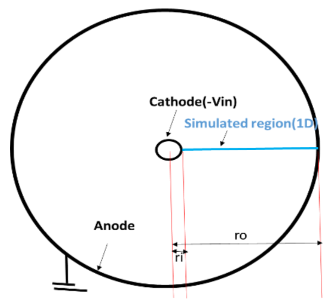

Fig. 1. An image of the simulation geometry and electrodes

2. STRUCTURE AND EQUATIONS

According to Figure 1, the discharge phenomenon of diffusion is considered uniform in the radial direction. In this model, the continuity of electrons and ions and the "drift-diffusion" motion equations, the self-continuity is coupled with Poisson's equations. In the presented model, the ionization of neutral gas (air) is investigated when a negative electric potential is applied to the inner electrode. The high electric field, which is caused by a combination of high electric potential and small bending radius of the conductor, leads to the flow of electrons and ionization of the gas around the cathode. The created positive ions, as a result of the secondary impact, produce more free electrons on the surface of the cathode. These electrons move away from the cathode by receiving the necessary energy in a small area. As a result of continued gas ionization, more electron pairs are released. Secondary ions move towards the cathode. The electron density is calculated by solving the "drift-diffusion" equations.

$$\frac{\partial}{\partial t}(n_e) + \boldsymbol{\nabla} \cdot [-n_e[(\mu_e \cdot \boldsymbol{E}) - D_e \cdot \boldsymbol{\nabla} n_e] = R_{\ e} \quad (1)$$

The convective effect of electrons due to fluid movement is neglected. Electron diffusion is calculated from the following equation.

$$\mathrm{De} = \mu_e T_e \quad (2)$$

$$\mu_\varepsilon = 5/3\mu_e \quad (3)$$

$$D_\varepsilon = \mu_\varepsilon T_e \quad (4)$$

Assuming that "M" is the reactions related to the growth and decay of the electron density and "P" is the number of inelastic collisions of electrons. Considering "P >>M" we have:

$$R_e = \sum_{j=1}^{M} x_j\, k_j \quad (5)$$

where "xj" is the mole fraction of the target species in the discharge process for reaction z, "kj" is the reaction rate coefficient and "N" is the total number density of neutral particles. Electron energy loss is obtained by summing the collision energy losses in all reactions:

$$R_\varepsilon = \sum_{j=1}^{P} x_j\, k_j N_n n_e \Delta\varepsilon_j \quad (6)$$

In the above equation, "$\Delta\varepsilon_j$" is the energy loss from reaction "j". The ratio of constants is calculated with the following integral:

$$k_k = \gamma \int_0^\infty \varepsilon\, \sigma_k(\varepsilon) f(\varepsilon) d\varepsilon \quad (7)$$

In the above equation, "$\gamma = \sqrt{2q/m_e}$", " m_e "electron mass" ε " energy, "σ_k " Collision cross section, "f" is a function of electron energy distribution.

The static electric field is calculated from the following equation.

$$-\nabla \cdot \varepsilon_0 \varepsilon_r \nabla V = \rho \quad (8)$$

$$\rho = \sum_{K=1}^{N} z_K\, n_k - n_e \quad (9)$$

Space charge density is automatically determined based on plasma chemistry and the formula above.

3. BOUNDARY CONDITIONS

Due to the random movement of electrons in the chamber, they disappear in several free paths upon hitting the wall, and free electrons are formed again due to the effects of secondary diffusion, which leads to the following boundary condition:

$$\mathrm{n} \cdot \Gamma_e = (1/2)V_{e.th} n_e - \sum_P \gamma_P\, (\Gamma_P.\mathrm{n}) \quad (10)$$

nd the electron energy flux is calculated as follows:

$$\mathrm{n} \cdot \Gamma_\varepsilon = (5/6)V_{e.th} n_\varepsilon - \sum_P \varepsilon_P \gamma_P (\Gamma_P.\mathrm{n}) \quad (11)$$

The second term on the right side of equation 10 represents the increase of electrons due to secondary emission effects. " γ " represents the secondary diffusion coefficient. The second term in equation 11 shows the energy flux of secondary emission. "ε " represents the average energy of secondary electrons.

In order to simplify the simulation process, a step function for modeling V0 is considered as follows.

$$V = V_0 \tanh\,(t/\tau) \quad (12)$$

4. PLASMA CHEMISTRY

The chemistry of plasma produced in air can be very complex and involve many reactions. The main purpose of this model is to study the density profiles of charged particles and species. Table 1 shows the relevant chemical reactions.

Table 1. Related chemical reactions.

Reaction	Formula	Type	Δε(ev)
1	e+Ar=>e+Ar	Elastic	0
2	e+Ar=>e+Ars	Excitation	11.5
3	e+Ars=>e+Ar	Superelastic	-11.5
4	e+Ar=>2e+Ar^+	Ionization	15.8
5	e+Ars=>2e+Ar^+	Ionization	4.24
6	Ars+Ars=>e+Ar+Ar^+	Penning ionization	-
7	Ars+Ar=>Ar+Ar	Metastable quenching	-

In permanent state, the main charged species of plasma are ions. For this reason, in the initial conditions, the density of negatively and positively charged ions and electrons are the same.

Compared to other gases, a higher voltage is needed to create the phenomenon of electric discharge and corona in the air. This is due to the following two reasons.

1- The frequency of electron impact in air is high due to rotational movements.

2- Oxygen is electronegative.

Fig. 2 shows the density of electrons and positive and negative ions.

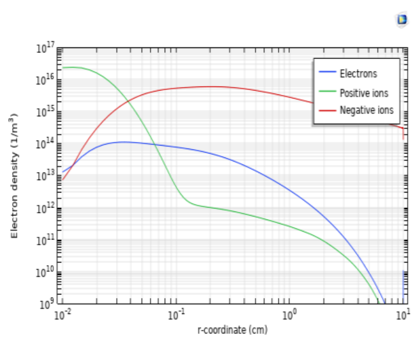

Fig. 2. Density of electrons and positive and negative ions.

Fig. 3 shows the temperature profile of electrons.

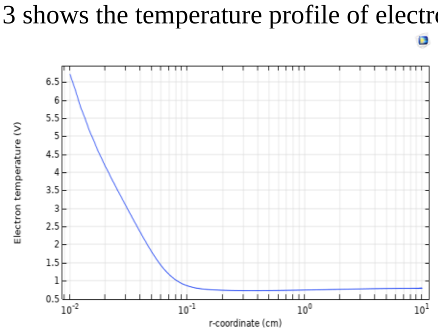

Fig .3. Electron temperature profile

Fig. 4 shows the electric potential profile.

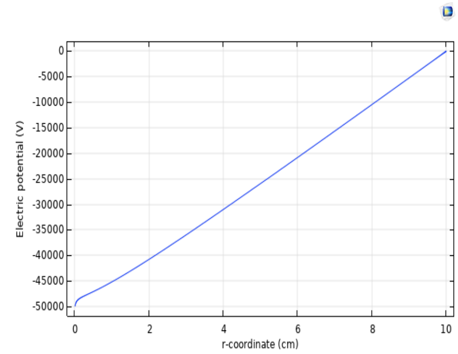

Fig. 4. Electric potential profile.

Fig. 5 shows the two-dimensional representation of the electron density.

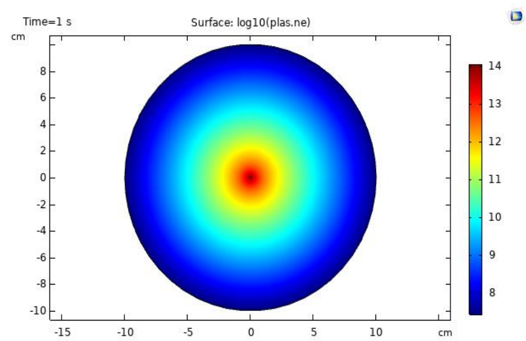

Fig. 5. Two-dimensional representation of electron density.

Fig. 6 shows the total ion current density in the grounded electrode in terms of input voltage.

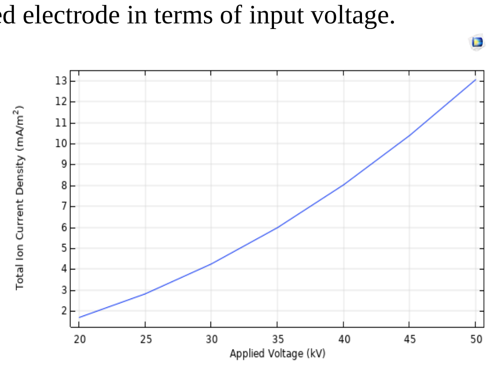

Fig. 6. the total current density of ions in the grounded electrode in terms of input voltage

5. CONCLUSION

The simulation of the mechanism and how to form the physical phenomenon of corona, i.e., the ionized air around the current-carrying conductor, in power networks, is done by COMSOL finite element software. In this model, electrical breakdown in an ionizable gas is investigated. Basically, to optimize the plasma production process and any other physical phenomenon, we model and simulate the desired phenomenon. The purpose of the simulation is whether it is possible to prevent the production of corona as a result of electrical breakdown caused by the ionization of the air around the conductor, which is often undesirable in power systems.

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