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The Knife-Plane Configuration Model of CCP equipment from plasma corona discharge case

Asep Yoyo Wardaya[1], Zaenul Muhlisin[2], Isnain Gunadi [3], Pandji Triadyaksa[4]

[1,2,3,4]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang Indonesia

ABSTRACT: This research discusses the concept of analytical calculations of current-voltage (I-V) characteristics in the case of corona discharges using an asymmetric electrode model (with a DC source), which is often called capacitively coupled plasma (CCP) equipment. This CCP equipment, which is almost similar in shape to capacitor equipment in conventional electrical equipment, has the characteristic of having an active electrode in an upright position above the position of a passive electrode (in a lying position) in the air. Another characteristic is that the lowest end of the active electrode has a sharp surface so that a large corona current flows out of the sharp surface towards the passive electrode. The (I-V) characteristic calculation method can be calculated using a geometric concept (based on the sharp surface at the tip of the active electrode) using a modified capacitance concept. For the case of an asymmetric model with an arrangement of active and passive electrodes perpendicular to each other, the capacitance calculation can use the knife-plane electrode configuration model.

KEYWORDS: CCP, asymmetric electrode model, (I-V) characteristics, corona discharge, geometric concept, knife-plane

I. INTRODUCTION

The use of plasma technology in various human lives has become commonplace, such as plasma applications in the Medical Field (Kim, & Kim, 2021), Agriculture and Biomedicine (Stryczewska, & Boiko, 2022), Plasma Fusion (Makar, 2020), etc. One of the plasma technologies used is electrode equipment, which is similar to a capacitor and is called capacitively coupled plasma (CCP). This CCP equipment is divided into three categories, namely the electric asymmetric CCP, the direct current CCP, and the dual-frequency CCP (Liu, et al. 2012).

There is an interesting thing in the discussion of plasma discharges, namely the discussion of the characteristics of current-voltage (I-V) that appear when using CCP equipment in the electric asymmetric and direct current categories. There is an oddity in the current-voltage (I-V) characteristics in the case of plasma discharges, which is not found in the case of (I-V) characteristics in ordinary conventional electric currents. This oddity can occur because the plasma discharge process is caused by several physical events such as electrodynamics (Guan, et al. 2018), convective heat transfer (Robinson, 1970), electric wind (Robinson, 1961), Etc. The solution for calculating the (I-V) characteristics is quite difficult to do because the calculations that have been carried out with physical solutions (using the concept of Maxwell's equations) only match part of the initial discharge curve. Although it is only suitable in the case of an initial discharge curve, there is a (I-V) characteristic model of the cylindrical CCP model that incorporates the concept of capacitance, which turns out to be suitable for symmetric discharge currents, as expressed by the equation (Robinson, 1967),

$$i = \frac{10^6}{l}\frac{4b_0 C_A}{\sigma R^2} V\left(V - V_i\right), \tag{1}$$

where i is corona current I/length l (A/m). The quantities R and l are the outer radius and length of the Coaxial Cylinders, respectively. The C_A quantity is the formulation of the capacitance of a cylindrical coaxial electrode (Halliday, et al. 2013), which can be written as

$$C_A = \frac{2\pi\varepsilon l}{\ln\left(R/r\right)}, \tag{2}$$

where r adalah radius dalam dari Coaxial silinder (thin wire). If you look at equation (1) above, the (*I-V*) characteristics apart from being determined by the capacitance value C_A, are also determined by a multiplier factor of 10^6, in addition to the outer radius

The Knife-Plane Configuration Model of CCP equipment from plasma corona discharge case

R.The appearance of the *R* factor in equation (1), identifies the symmetrical plasma flow from the inner cylinder to the outer cylinder, while the multiplier factor indicates the strength value of the plasma electric current which is much greater when compared to the electric current originating from an ordinary conventional circuit.Now, we will apply the capacitance model to the case of asymmetric CCP equipment using a DC source. For this case, of course, the plasma current that comes out is not symmetrical in shape from the active electrode to the passive electrode. This event can occur because the most dominant plasma discharge output (not evenly distributed to each electrode surface) will come out from the lowest end of the active electrode area with a tapered surface towards the passive electrode, in accordance with the experiment Dobranszky, et al. (2008).However, the capacitance concept can still be used, although the calculation must be modified according to the discharge conditions of the experiment Dobranszky, et al. (2008). This capacitance model is referred to as a modified capacitance model by adding a multiplier k from the sharpest area of the integration boundary of the capacitance calculation, as done by Wardaya et al. (2022,2022A).

II. KNIFE-PLANE ELECTRODE CONFIGURATION

To calculate capacitance with the active electrode in an upright position above the passive electrode (in a lying position below the active electrode), we need a knife-plane electrode configuration model illustrated in Figure 1 below

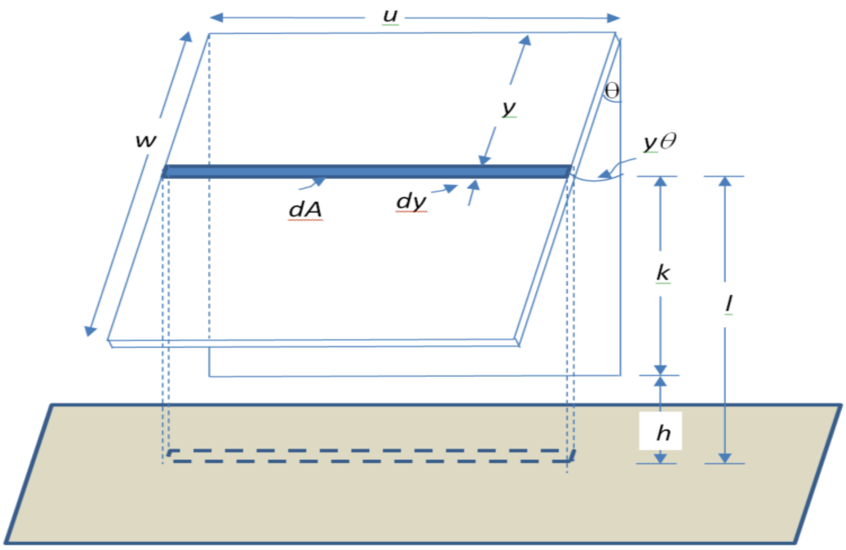


Figure 1. Sketch of the knife-plane electrode configuration model.

The picture above shows a sketch of the CCP equipment with a knife-plane electrode configuration model. The model begins with an active electrode (upper plate) inclined θ to the vertical plane. The active electrode has a length *u* and a width *w*, where if it is positioned perpendicularly in the air, it will have a *h* distance from the passive electrode (in a horizontal position below the active electrode).Now consider an area element *dA* (located at the active electrode) with a length *u* and a width *dy*. The distance of the area element to the top end of the active electrode is *y*, while the space of the area element to the passive electrode is *l* = *k* + *h*. If the area element represents the active electrode element, then the size of the capacitance element can be written as

$$dC = \varepsilon_0 \frac{dA}{l} = \varepsilon_0 \frac{u\,dy}{k+h} \ . \qquad (3)$$

For the case of the active electrode perpendicular to the passive electrode ($y\theta \cong 0$), which is called the knife-plane configuration model, the relationship $k = w - y$ is obtained so that for the plane knife configuration model, equation (3) can be written as

$$dC = -\varepsilon_0 \frac{u\,dy}{(y-w-h)} \ . \qquad (4)$$

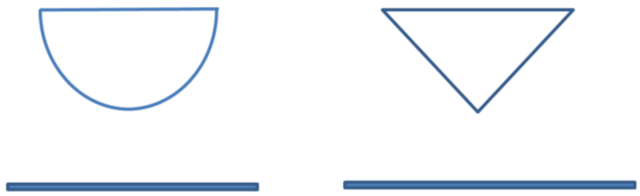
The solution of the capacitance value from the plane blade configuration model, from equation (4), by considering the boundary conditions $0 \le y \le w$, will produce the equation.

$$C_h = -\varepsilon_0 u \int_{y=0}^{w} \frac{dy}{(y-w-h)} = \varepsilon_0 u \ln\left|\frac{w}{h}+1\right| . \qquad (5)$$

The Knife-Plane Configuration Model of CCP equipment from plasma corona discharge case

III. APPLICATION ON CCP EQUIPMENT

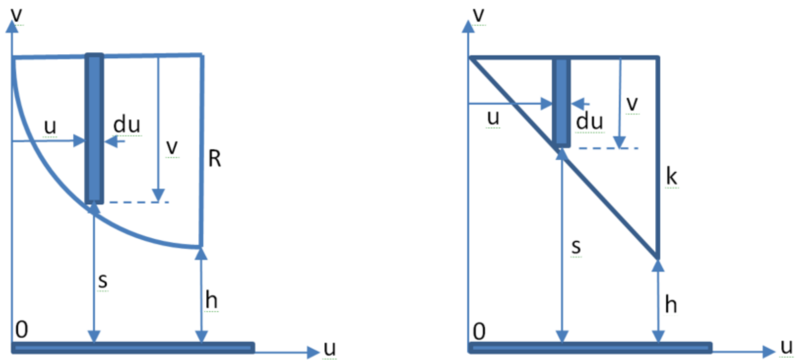
For the case of various CCP equipment with the active electrode in the form of a thin plate and with the plate positioned perpendicularly in the air, while the passive electrode is in the form of a wide rectangular plate and its position lies horizontally below the active electrode, the capacitance calculation can be calculated using equation (5) above. For example, we will look at 2 electrode configuration models of CCP equipment as illustrated in Figure 2 below,



(a) (b)

Figure 2. Sketch view of 2 electrode configuration models of CCP equipment. (a). The active electrode is a semicircle, and (b) The active electrode is an isosceles triangle. All passive electrodes are rectangular plates that lie horizontally below the active electrode.

To calculate the capacitance of the two models above, the first thing to look at is the symmetry of the active electrode, so the capacitance value is calculated using Figure 3 below.



(a) (b)

Figure 3. Example of a capacitance value calculation model. (a). The active electrode is a semicircle, and (b) The active electrode is an isosceles triangle.

Calculating the capacitance value from Figure 2 can use the principle of symmetry where the shape of the active electrode in Figure (2) only takes up half of it, which is seen in Figure (3). From Figure (3), we can calculate the capacitance element through the formula

$$dC_k = \varepsilon_0 \int_u du \ln\left|\frac{v}{s}+1\right|. \qquad (6)$$

From equation (6), we can calculate the capacitance value of the electrode configuration system in figure (2), with the total capacitance value being $C_{tot} = 2C_k$ because it uses the symmetry principle. In Figure (3), there is also a length relationship that connects the size of the electrode element with the actual electrode, such as:

$s + v = R + h$ (in picture (3a)) and $s + v = k + h$ (in picture (3b)). (7)There is an additional concept for the modified capacitance model, namely the emergence of a current multiplication factor k at the integration boundary of the sharp, active electrode area, thus producing a modified capacitance value C_{tot}. In Figure 3, the position of the site with a tapered shape is the position of the bottom electrode tip, which is a distance h from the passive electrode. For the (I-V) characteristic formulation, we can use the formulation introduced by Wardaya et al. (2022,2022A) as

$$I = -\frac{\mu_0}{\varepsilon_0^2}\left[\frac{\{C_{tot}\}^3}{(\text{Gauss area})^2}\right](V-V_i)^2. \qquad (8)$$

IV. DISCUSSION

The Knife-Plane Configuration Model of CCP equipment from plasma corona discharge case

Problems that arise from calculating the current-voltage (I-V) characteristics of corona discharge cases in CCP equipment can be solved using physical calculations (using Maxwell's equations) or geometrically (using a modified capacitance approach). For geometric calculations in the case of asymmetric CCP and DC source, the modified capacitance calculation using a knife-plane model approach applies to the condition that the active electrode is made of a thin plate and has a perpendicular position in the air with the passive electrode below the active electrode in a horizontal position.

V. CONCLUSIONS

This research uses a geometric approach to calculate the knife-plane configuration model for modified capacitance calculations in calculating the (I-V) characteristics of the plasma discharge case. The physical or geometric approach method only represents the initial discharge curve part of the (I-V) characteristic graph, where the continuation curve of the (I-V) characteristic is quite difficult to predict because of the complexity of the physical problems that occur in corona discharge events. Using a modified capacitance model by introducing a k factor as a fitting curve is a relatively straightforward approach to calculating (I-V) characteristics compared to the physical solution approach using Maxwell's equations.

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