Investigation of the Barriers Influence in the Air Gap Point-Plane by Electric Field Estimation

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***Abstract*—In this paper ,we develop a model for three computation of the electric field in the presence of a space charge which is given in its turn after the knowledge of the effective ionization factor. The effect of the barriers in the intervals of air point-plan was the subject of several investigations; those showed that the influence of the barrier is especially related to the accumulation of loads on its surface on the active electrode side. Thus the barrier constitutes a mechanical and electrostatic obstacle with the increase in discharge. From an economic standpoint, the quality and dimensions of the barrier should not be the only criteria for the insulation coordination, in each system of HV electrodes. Results show that electric stress in the air gap decreases due to space charge left in the point-barrier gap, but it increases suddenly at the handle of the avalanches and on the upper barrier surface. This later effect related to the presence of the dielectric barrier is due to the polarization charge.**

Keywords—Streamer, Electric field, Space Charge Barrier, Ionization Factors, Point-Plane, FVM

I. Introduction

The design of high voltage systems requires the knowledge of electric field and potential distributions of specific HV arrangement. One of the way for increasing a long point-plane air gap electric strength is to incorporate insulating a barrier [l]. The propagation velocity of steamers and electrons are not related to one another since the progress of the stream rather results from the effectiveness of the electron multiplication process in that an avalanche of electron velocity themselves. The increase in electric strength for this arrangement is obtained in the case were the HV point polarity is positive, in the case of the negative polarity, no increase was obtained the discharge phenomena being different [l]. It leads to an electric field redistribution in the electrodes gap. It has been admitted [1-2] that, this effect consists in the field uniformity between the barrier and the plane. This uniformity is itself owing to the positive space charge accumulated on the barrier surface facing the point [2] .In addition, a large number of avalanche can simultaneously contribute to the spread of the streamer as it has been shown previously. The propagation of a streamer in a non uniform field [3] necessarily causes the tracing of the inter - electrode gap as in the case of a uniform Electric field various breakdown criteria are based on the knowledge of efficient ionization factor α. The dependency of α to the non-uniform applied field is known with an acceptable reliability for the experimental data base given by Geballe and Harisson with p = 760 torrs (p is the atmospheric pressure) [3]. The applied electric field magnitude E_0 in the meantime before the formation of the space charge is required. Since the ionization pressure factor (α / p) depends on the size of E_0 / P,the test streamer can be given by equation (1). The application of this equation is confronted with some problems according to the electric field distribution. This distribution changes from one configuration to another according to the radius of curvature of the point and the length of the air gap point-plane [1-2].

The transition to streamer can, be written as[4]:

$$\int_0^{Xc} \bar{\alpha}\ .dx \geq 18 \tag{1}$$

Xc : Is the length of the avalanche from the HT peak.

The left side of the inequality states that the effective ionization takes place in the region of the field.

II. ACTIVE ELECTRIC FIELDS CALCULATIONIN THE POINT BARRIER-PLANE AIR GAP

The distribution of the field can be determined from the theoretical calculation of the field or by measurement. The theoretical calculation is made to obtain the field. Strength across the inter-electrode while the measurement allows the surface area of the electrodes [7-9].

A. Applied field in a Pointe-plan system E_0

At voltage V, the field E_0 isexpressedin spherical coordinateselongated in the absence of the barrier by[9]:

$$E_0 = \frac{V}{a\sqrt{(1+c_1)+\left(1-\frac{z^2}{a^2c_1}\right)}\sqrt{1-\frac{z^2}{a^2c_1}}.\ lncot(\frac{\theta_I}{2})} \tag{2}$$

With:

θ_1 :Angle between Y-axis and the HV point.

a_i :The point focus-plane distance

V : Applied voltage..

$$\Delta = x^2 + z^2 - a^2 + 4a^2 z^2 \quad (3)$$

$$c_1 = \frac{x^2+z^2-a^2+\sqrt{\Delta}}{2a^2} \geq 1 \quad (4)$$

See the influence of the curvature radius Δρ of the HT which is a very important parameter in the shock theories, given in a form as follows:

$$\Delta\rho = a_i tg^2\theta_I \quad (5)$$

B. Field due to the space charge (E_R):

Before starting the calculation of E_R , one must first calculate the amount of space charge created in the air gap-tip without barrier under the effect of the applied field E_0 . Calculation of the space charge, The number of positive ions is calculated as follows:

- For planar electrodes:

$$\mathrm{n} = \mathrm{n}_0[\varepsilon\xi\pi(\alpha \mathrm{x}) - 1] \quad (6)$$

For another type of electrode or non-uniform field, the quantity(α) will be a function of the source field (E_0) and thus write:

$$n = n_0\left[\exp\left(\int_0^{x_c} \alpha\, dx\right) - 1\right] \quad (7)$$

Photo-ionization phenomena are not taken into account explicitly, but implicitly in the calculation of the system stiffness. This is achieved by basing the calculations on the criterion of streamers, because the formation of a streamer is expressed through the mechanism of photo-ionization occurring within the primary avalanche [11-16]. It calculates the number of positive ions following the steps listed below: From the calculation of the applied field on each point E_0 and having a database ionization factor α = f (E / P) is given by Harrison and Geballe . A is selected at every point , taking the conditions of pressure p = 760 Torr[11-16] . Determining the length of the avalanche Xc from the HTpoint in the region or the ionization process occurred by electron collision.Having obtained x_c in each node, we calculate the integral : $\int_0^{x_c} \alpha\ dx$

The calculation of the number of initial electron n_0 is made based on the value of the saturation current of air (i_s) for planar electrodes. Knowing the geometric factor $\beta = \frac{E_{max}}{E_{MOY}}$ for hyperboloidal electrode, we have:

$$i_0 = i_s\beta. \quad (8)$$

i_0 : is the current dissipated in the air, the application of HT , and from the initial chargeq_0, finally determines :

$$n_0 = \frac{q_0}{e} \quad (9)$$

e : is the elementary charge of an electron.

Finally the space charge is given by:

$$q = e.n_0\left[\exp\left(\int_0^{x_c} \alpha\, dx\right) - 1\right] \quad (10)$$

For low values of the applied field (α<0) , the ionization has not occurred , so the space charge is zero at this point.

C. Calculation of the fields space charge$E_R$by Gauss method

The non-uniform distribution of the space charge has came as a result of dependence of the ionization factor α to the value of field E_0 [5-6],[10]. This allocation requires the approximate volume taken up by the load by an equivalent geometry. In our study we chose half concentric sphere whose center is the HT tip and the outer radius is determined by the maximum distance from the HV point beyond which α = 0. This rating is equivalent to the electrodes geometry whose corresponding equipotential lines have a shape close to that of a sphere (hyperboloid, sphere, parabola,....).The radius of each hemisphere describes a volume in which the ionization factor α is constant. Note that the effect of space charge is subtracted from the intervalE_0 in tip barrier. If the load is located between the barrier and the plan, its effect will be added to the appliedE_0. We consider that all ionization phenomenon do not exist below the nesting.

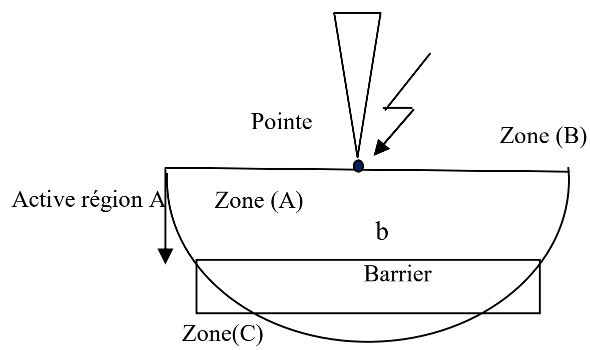

Fig.1. Global Shape equivalent volume occupied by the load space

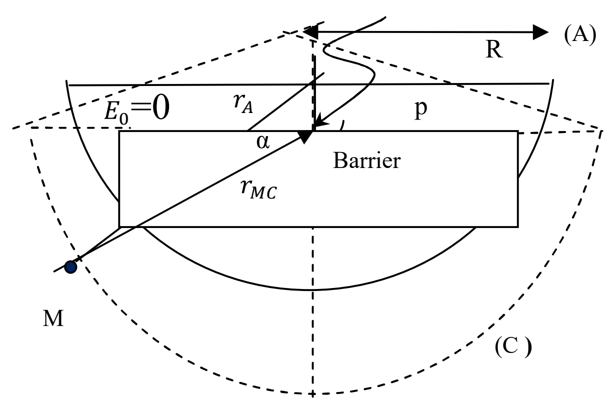

Fig.2. Calculation of$\vec{E}_R$ by method of gauss

The density of charge vanishes when we cross to another concentric half sphere. Then ,the field at an arbitrary point M (Fig.2) is given by equations below:

$$E_R = \frac{\phi_A}{2\pi r_A^2} - \frac{\phi_c}{4\pi . r_{MC}^2 . \alpha} \quad (11)$$

$$\phi_A = \sum_{i=1}^{m} \frac{q_0[\exp(\alpha_i r_i)-1]}{\varepsilon_0} V_{Ai} \quad (12)$$

Nis: the total number of concentric half-spheres, r_i is theradius of the i[th]half- sphere and α_i is the efficient ionizationfactor in the i[th]half- sphere. q_0 is the positive ions charge just after the application of the HV and V_{Ai}.

m : number of radius of concentric half-spheres.

V_{Ai} :volume of the ith half-sphere described by the i[th]radiusr_i where α_i is constant.

$$\phi_c = \sum_{i=1}^{m} \frac{q_0[\exp(\alpha_i r_i)-1]}{\varepsilon_0} V_{ci} \quad (13)$$

m :number of radius of half-spheres which overstep the barrier surface facing the point.

V_{ci}:volume limited by the screen surface facing the point and the i[th]radiusr_i.

III. FINITE VOLUME(FVM) FORMULATION IN EACH DOMAIN ZONE

A. Zone –Pointe- Barrier gap(zone 1)

Different active fields in zone 1 are :

$$\vec{E}_1 = \vec{E}_0 + \vec{E}_R + \vec{E}_d \quad (14)$$

We have:

By combining this equation with the Maxwell given by:

$$div\vec{E}_1 = \rho \quad (15)$$

Finally:

$$\varepsilon_0\, div\vec{E}_0 + \varepsilon_0 div\vec{E}_R - \varepsilon_0 . \Delta\psi = \rho \quad (16)$$

Resolution by the finite volume method [13]

We integrate the differential equation (16) on the corresponding node finite volume P is obtained

$$\iint_{sw}^{ne} \frac{1}{r}\frac{\partial}{\partial r}(rE_{0r})rdrd\theta + \iint_{sw}^{ne} \frac{1}{r}\left(\frac{\partial E_{0\theta}}{\partial\theta}\right)rdrd\theta + \iint_{sw}^{ne} \frac{1}{r}\frac{\partial}{\partial r}(rE_{Rr})rdrd\theta + \iint_{sw}^{ne} \frac{1}{r}\left(\frac{\partial E_{R\theta}}{\partial\theta}\right)rdrd\theta - \left[\iint_{sw}^{ne} \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\psi}{\partial r}\right)rdrd\theta + \iint_{sw}^{ne} \frac{1}{r^2}\left(\frac{\partial^2\psi}{\partial\theta^2}\right)rdrd\theta\right] = \frac{\rho}{\varepsilon_0} \quad (17)$$

B. In The barrier (Zone 2)

In the barrier, we have:

$$\vec{E}_2 = \vec{E}_1 + \vec{E}'_d \quad (18)$$

$\vec{E}'_d$: Dipole field in the dielectric.

$\vec{E}_d$: Dipole field outside of the dielectric.

σ_P : Surface bound polarization charge, the dipole field is not the same inside and outside of the same dielectric in absence of a free charge on the interface

ρ_s : :Charge of surface space on the upper side of the barrier The dipole field in the barrier is given by:

$$E'_d = \frac{-(\varepsilon-\varepsilon_0)(\varepsilon_0 E_{n1}+\rho_S)}{\varepsilon^2} + \frac{\varepsilon_0}{\varepsilon}E_{dn} \quad (19)$$

E_{dn} and E_{n1} respectively, the normal components of bias field and E_1

$$\overrightarrow{E_2} = \overrightarrow{E_1} + \left(-\frac{(\varepsilon-\varepsilon_0)(\varepsilon_0 E_{n1}+\rho_S)}{\varepsilon^2} + \frac{\varepsilon_0}{\varepsilon}E_{dn}\right)\vec{J} \quad (20)$$

Resolution by the finite volume method:

$$\iint_{sw}^{ne} \frac{\varepsilon}{r}\frac{\partial}{\partial r}(rE_{0r})rdrd\theta + \iint_{sw}^{ne} \frac{\varepsilon}{r}\left(\frac{\partial E_{0\theta}}{\partial\theta}\right)rdrd\theta + \iint_{sw}^{ne} \frac{\varepsilon}{r}\frac{\partial}{\partial r}(rE_{Rr})rdrd\theta + \iint_{sw}^{ne} \frac{\varepsilon}{r}\left(\frac{\partial E_{R\theta}}{\partial\theta}\right)rdrd\theta - \iint_{sw}^{ne} \frac{\varepsilon}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\psi}{\partial r}\right)rdrd\theta - \iint_{sw}^{ne} \frac{\varepsilon}{r^2}\left(\frac{\partial^2\psi}{\partial\theta^2}\right)rdrd\theta + \iint_{sw}^{ne} \left[\frac{(\varepsilon-\varepsilon_0)\varepsilon_0}{\varepsilon}\left(\frac{\partial E_{0r}}{\partial r} - \frac{\partial E_{Rr}}{\partial r}\right)\right]rdrd\theta - \iint_{sw}^{ne} \left[\left(\frac{(\varepsilon-\varepsilon_0)\varepsilon_0}{\varepsilon} + \varepsilon_0\right)\frac{\partial^2\psi}{\partial r^2}\right]rdrd\theta = 0 \quad (21)$$

C. Zone barrier – Plan gap(Zone 3)

The different fields in the active area (3) are :

$$\vec{E}_3 = \vec{E}_2 + \vec{E}_d'' \quad (22)$$

Resolution by the finite volume method:

$$\iint_{sw}^{ne} \frac{\varepsilon_0}{r}\frac{\partial}{\partial r}(rE_{0r})rdrd\theta + \iint_{sw}^{ne} \frac{\varepsilon_0}{r}\left(\frac{\partial E_{0\theta}}{\partial \theta}\right)rdrd\theta +$$

$$\iint_{sw}^{ne} \frac{\varepsilon_0}{r}\frac{\partial}{\partial r}(rE_{Rr})rdrd\theta + \iint_{sw}^{ne} \frac{\varepsilon_0}{r}\left(\frac{\partial E_{R\theta}}{\partial \theta}\right)rdrd\theta$$

$$-\iint_{sw}^{ne} \frac{\varepsilon_0}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \psi}{\partial r}\right)rdrd\theta - \iint_{sw}^{ne} \frac{\varepsilon_0}{r^2}\left(\frac{\partial^2 \psi}{\partial \theta^2}\right)rdrd\theta +$$

$$\iint_{sw}^{ne}\left[\frac{(\varepsilon-\varepsilon_0)}{\varepsilon_r^2}\left(\frac{\partial E_{0r}}{\partial r} - \frac{\partial E_{Rr}}{\partial r}\right)\right]rdrd\theta -$$

$$\iint_{sw}^{ne}\left[\left[\varepsilon_0\left(1-\frac{1}{\varepsilon_r^2}\right)+2\varepsilon\right]\frac{\partial^2\psi}{\partial r^2}\right]rdrd\theta = \rho \quad (23)$$

TABLE I.

Symbol	Quantity
$\bar{\alpha},\alpha$	Coefficient ionization and ionization factors, respectively
β	Geometric factor
(C)	Calotte of (A) limited by barrier and angle limited by barrier level and Gauss surface for each $\vec{E}_R$ Calculation in arbitrary point
(A)	Half-sphere enclosing all produced space charge
A	Distance from HV electrode focus to plane
$\varepsilon_0, \varepsilon_r$	Permittivity and relative permittivity of barrier, respectively
θ_I	Angle determining HV point radius
Θ	Angle between z-axis and asymptotes of hyperboloids, which are équipotential surfaces
q0	Initial charge near point just after application of HV
V	Applied high voltage
r_A	Radius of Gauss surface
r_{MC}	Distance between barrier centre and arbitrary point M to calculate $\vec{E}_R$
r_i	Radius of with concentric half-sphere
η	Attachment factor
ϕ_A, ϕ_C	Electrical flux crossing, respectively, (A) and (C)

Symbol	Quantity
$\vec{E}_1, \vec{E}_2, \vec{E}_3$	Resultant electric fields, respectively, in zone1,2, 3
$\vec{E}_0$	Applied electric field
$\vec{E}_R$	Space-charge generated field
Ψ	Polarization potential
$\vec{E}_d', \vec{E}_d''$	Polarization field and its normal component, respectively
P	Space-charge density

IV. RESULTS AND DISCUTIONS

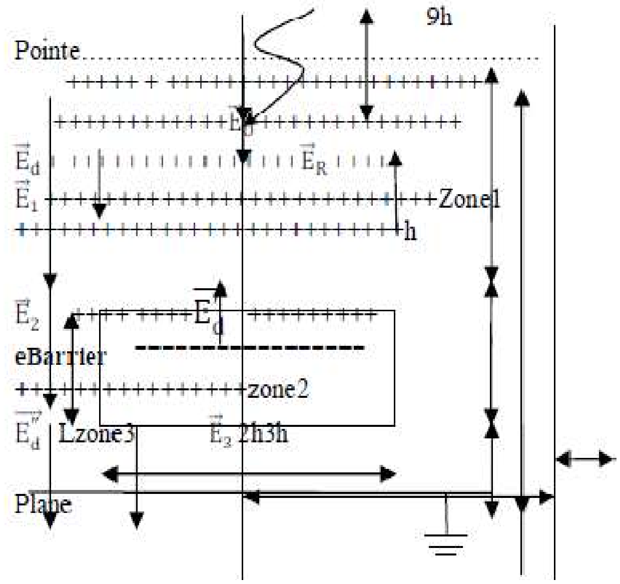

Fig.3. Active fields in each zone ofthe regionproblem and dimension of sued arrangement

For analysis the constant parameters used are as follows

The barrier is square shaped of 1m side and 5mm thick. This empirical value of the thickness is sufficient to prevent the electric breakdown of the barrier .The electrodes gap is 1m long. The distance between the point and the upper boundary of the problem region and between the barrier edge and the longitudinal boundary are given in figure (3). Such values minimize the disturbance effect of stray capacities. The distance between the tip and the upper side of the field is 9m. With this distance, we have a field which is practically zero on the domain boundaries, relative to its value in the tip range. To also ensure that all field lines are channeled towards the plane grounded, while avoiding the edge effect. In the latter, it is chosen a circular form with a radius of 2h. This dimension corresponds to that used in practice .We made a study for any of the barrier positions against a tip equal to 20% of the range point map corresponding to the optimal position determined experimentally. For the problem modeling, we took a graduation to study oxy orthonormality whose origin is the plan center, ox is the lower side of the field and or passes through the axis of the high-voltage ,the tip is a hyperboloid shape ($\alpha = 10^0$).

A. The field along the tip axis (from the plan)

The figures giving the field along the tip axis allow us to see the space influence on the field distribution on the interval peak load plan and the electrostatic influence of the barrier.

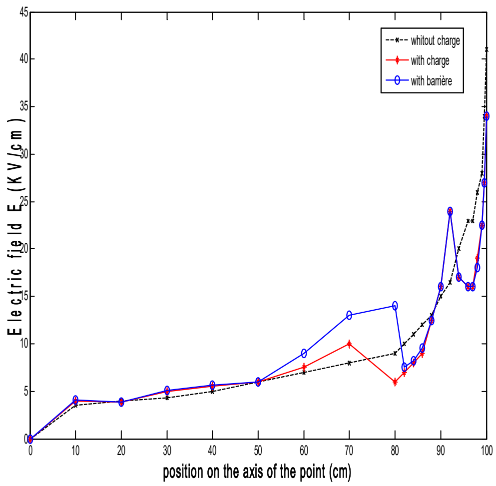

Fig.4. Electric field on the axis of the tip in the absence barrier with and without space charge V=700Kv,$\varepsilon_r = 4, \alpha = 10^0$

The field is reduced and get more uniform when we approach the plane, so we can divide the system into three sub systems: Pointe-barrier, barrier and barrier with background. The space charge enhances the field in the tip range 90<x<95. After that, lowering the load has a reducing effect on the field. On the upper side of the barrier, the tangential field is arrimage to growth under the influence of the space charge when the latter exists on the barrier surface. This influence is especially noticeable in air field reduction. In our case $\rho_s = 0$, the field has surged over the fence (x=80cm), and then decreases to standardize barrier in between the scenes. The increase in the field on the barrier is due to the polarization superficial charge [5].

B. Calculation of the electric field in a range with air barrier

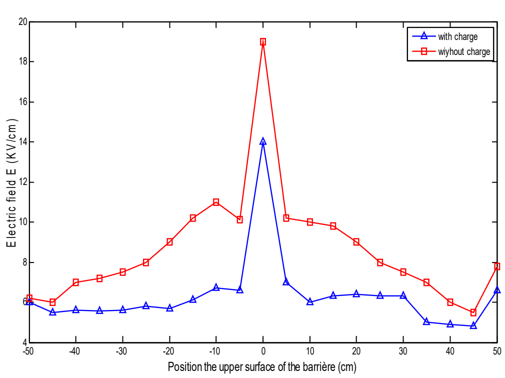

Fig.5. Electric field on the upper side of the barrier with and without space charge V=700Kv,$\varepsilon_r = 4, \alpha = 10^0$

The field on the barrier upper surface and the free charge when no longer exists (the case of our work). The bias field can not be neglected. Therefore, the scope of the barrier is greater than the field at a level corresponding to the barrier in the case of its presence. The surface charge is zero in this case, the field from which the barrier is strengthened by the bias field which is convergent toward the barrier.

C. Influence of the voltage level

We present the figure giving the influence of the applied voltage, the first graph presents the cover indicating that the voltage is excluded from this study provided that a test of strength that we do in the calculated field around the tip.

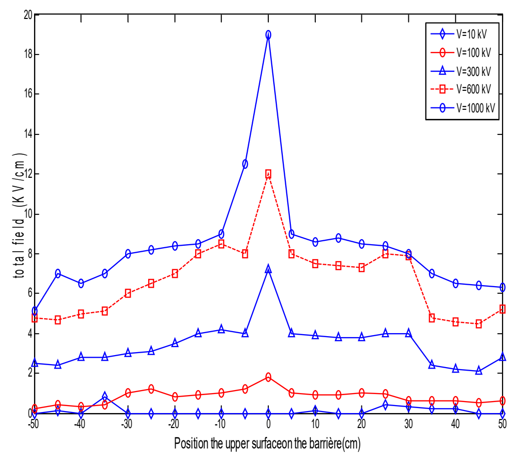

Fig.6. Field on the upper surface of the barrier different voltage levels$\varepsilon_r = 4, \alpha = 10^0$

The experience to give a range of 1 m under an alternating current of 50 Hz, the spark discharge voltage is in the order of 735 kV. [1] The effect of applied voltage level is especially clear in the case of 1000kV, the edge effect of the barrier is remarkable.

D. Influence of the opening angle of the tip (radius curvature)

On the axis passing through the edge of the barrier

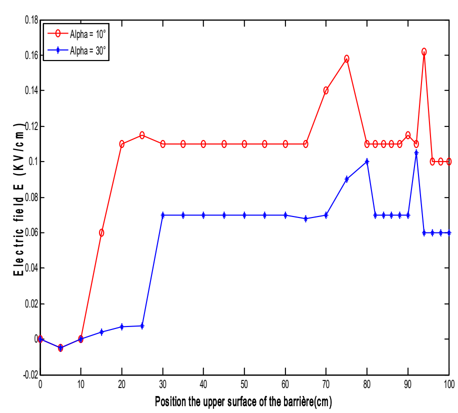

Fig.7. Electric field on the side of an insulating barrier to two different openings of the tip angle V=100Kv $\varepsilon_r = 4$

The field is uniform in the plan barrier are a 0<X <79.5 cm, it marks a uniform jump at the fence, strength hens a second time zone or agglomerates space charge and finally decreases at the tip.

V. CONCLUSION

In this paper, a model is developed for the computation of the electric field and potential in the presence of a space charge, which is determined from the knowledge of the efficient ionisation factor. The choice for solving these equations, numerical tool such as the finite volume method based on a main discretization seems to be an economic indicator and simple to implement. A numerical method such as the Gauss- Seidel coupled to the relaxation method is adopted well to nonlinearity in the study of the electrostatic problem. The total electric field in the gap limited by the HV electrode and the barrier decreases in the region left by the space charge. At the handle of avalanches and on the barrier surface, the stress increases suddenly. In the barrier-plane gap, the electric field is uniform. Due to the polarization. The effect of the space charge fields is to reduce the breakdown voltage.

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