J. Basic. Appl. Sci. Res., 2(1)406-414, 2012
© 2012, TextRoad Publication
ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Investigation the Effect of Ion Diffusion on Power Loss Transmission Lines Due to Air Insulation Ionization Using ANSYS

[1]Behruz Alefy , [2]Mansour Hosseini Firouz , and [3]Mohammad Mohammadi

[1,2,3] Department of Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran

ABSTRACT

This paper investigate the effect of considering ion diffusion on the corona loss in HVDC transmission lines using Finite Element Method (FEM).In first study, ion diffusion is not considered, In second study the effect of ion diffusion as constant parameter has been considered and finally in this paper the effect of ion diffusion coefficient is taken in account as function of electric field in calculation of power corona loss. In paper programming calls for only one loop and a new approach for updating of space charge densities around the conductor is implemented using Rung-Kutta integration method. The proposed method of solution has been applied for laboratory and full scale models of unipolar conductor to plane configuration.
KEY WORDS: Corona, Corona Power Loss, ion diffusion coefficient, Finite Element method(FEM) Engineering.

I. INTRODUCTION

HVDC and HVAC transmission lines power corona loss is one of the main problems. It is one of main active power loss in transmission lines [1]. So it is necessary to try to calculate it precisely and to try to decease it. Many attempts were made to solve ionized field using Charge Simulation Method (CSM)[2],Boundary Element Method[3]and Finite Element Method[4],[5].

One of main parameter in corona loss calculation is ion diffusion coefficient. In previous works, this factor has not considered or it has considered as constant value. But in this investigation this parameter has been considered as function of electrical field and results of this assumption on simulation results are analyzed and compared with other simulation results.

But none of them has been taken in account the effect of the diffusion coefficient as function of electric field and climate temperature and air density, ect.

The present method implements the potentials and electric field at conductor surface as boundary conditions, however; in previous method [6-7] deal only with the potentials in conductor and ground plane and check the field on conductor surface later.

II. Unipolar Corona Field Equations

The main system of equations describing unipolar DC corona is as follows:

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \qquad (1)$$

$$\nabla \cdot \vec{J} = 0 \qquad (2)$$

$$\vec{J} = k\rho\vec{E} - D\nabla\rho \qquad (3)$$

$$\vec{E} = -\nabla\Phi \qquad (4)$$

(1) is Gauss's low relating electric field intensity E to the space charge ρ and ε_0 is the permittivity of air. The next equation is the continuity equation for current density $\vec{j}$

(3) is the relation between the electric field ions and current density $\vec{j}$ where k is ion mobility and D is ion diffusion coefficient. The last equation is the electric field in terms of potential Φ .

In this study for equation (3) three case studies have considered as follow:

Case 1: The ion diffusion is neglected and is supposed to be zero.
Case 2: The ion diffusion is supposed to be constant parameter.
Case 3: The ion diffusion is supposed to be function of electrical intensity.

III. Simplifications in calculation process

All attempts reported before were based on some simplifying [6-8].the most common ones are:

a)The entire electrode spacing is filled with unipolar space charge of the same polarity as the coronating conductor.

Corresponding Author: Behruz Alefy, Department of Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran,Email:Beh_alfi@yahoo.com

b)The space charge affects the only the magnitude and not the direction of the electric field .this assumption was suggested at first by Deutsch and take referred to as "Deutsch's assumption".
c)The mobility of ions is constant (independent of electric field intensity).
d)The surface field of the coronating conductor remains at onset value E_0, which is known as Kaptzov's assumption [7]. For conductor to plane configuration E_0 is expressed in kV/cm as [7]:

$$E0 = 30\eta[1+\sqrt{(0.0906 / R]}\quad kV / cm \qquad (5)$$

In another assumption [9], the electric field E_c at coronating conductor surface is assumed to be a function of applied voltage, i.e.

$$E_{crit} = E_0 f_1(V / V_0) \qquad (6)$$

Where f_1 is assumed to have the following forms:

$$f_1(V / V_0) = 1.1339 - 0.1678(\frac{V}{V_0}) + 0.03(\frac{V}{V_0})^2 \qquad (7)$$

With f_1 assumed to be unity at $V = V_0$, where V_0 is the corona onset voltage.
In this paper the assumption (d) is neglected and the magnitude of electric field at conductor surface for updating space charges is evaluated in each step with FEM method by ANSYS software and used in next step for integration of space charge for updating along electric field lines

IV. Boundary conditions

Solution of the equations describing the space-charge modified field requires all three boundary conditions as follows:

(a) The potential on the ground plane is zero.
(b) The potential on the coronating conductor is equal to the applied voltage.
(c) The magnitude of the electric field in each step of simulation was calculated by ANSYS and it used in integration process of updating space charges.

The boundary conditions (a) and (b) were applied in model construction in ANSYS and the third boundary condition was implemented in integration process.

V. Proposed Method Of Analysis

The proposed method is described follow:

A- Configuration of model:

For the conductor to plane configuration, a conductor of radius R is located at a height H above the grounded plane, Fig.1.

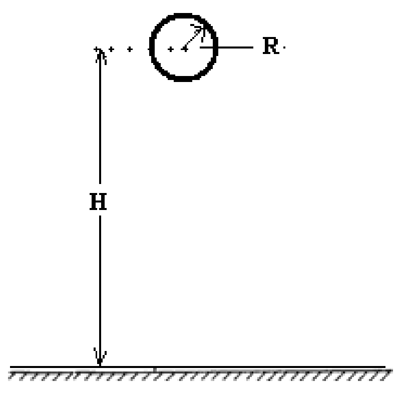


Fig.1. the conductor to plane configuration

The proposed method is described follow:

B- Mesh Generation:

Whereas the calculation of electric field and potential was performed using FEM method, therefore the model must to be meshed. The meshing process was made with triangular element, Fig.2.

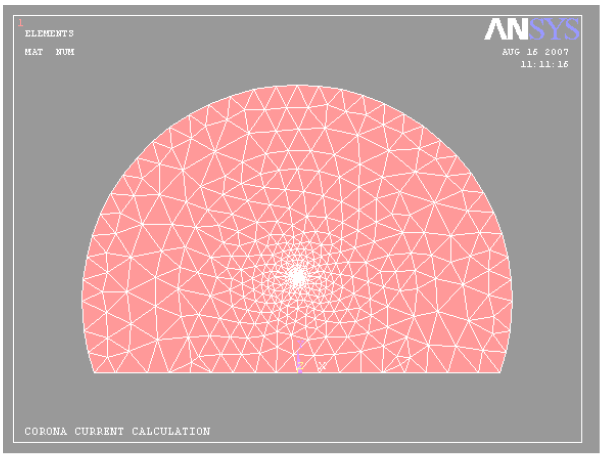


Fig.2.Generated mesh with ANSYS by triangular element

It is well known that FEM calls for bounded regions in which the mesh to be generated. Hence as it has been shown in Fig.2, fictitious boundaries X1-X2 and R_{out} are assumed around the discharging conductor. This choice was found to be satisfactory in light of the fact the computed results did not change for larger value of X1-X2 and , R_{out} ,[5].

Because R_{out} is not at infinity, the potential of the nodes at fictitious boundary, R_{out} , is not zero, but the potential at X1-X2 is equal to potential of ground plane and is equal to zero.

C- First estimation of space charges:

The configuration considered in the present method consists of a single cylinder of radius R of a height H above the grounded plane.

The bipolar co-ordinates α and β , shown in Fig.3, are employed, which are related to the Cartesian co-ordinates x and y by following relations [9]:

$$y = \frac{a}{s}\sinh\beta \quad , \quad y = \frac{a}{s}\sinh\beta \tag{8}$$

Where:

$$a = (H^2 - r_c^2)^{1/2} \text{ , } s = \cosh\beta + \cos\alpha \tag{9}$$

The metric coefficients are given by the following expressions:

$$h_\beta = h_\alpha = \frac{a}{s} \tag{10}$$

And the co-ordinates of coronating conductor and ground plane are given by:

$$\beta_c = \cosh^{-1}\left(\frac{H}{r_c}\right), \beta_g = 0 \tag{11}$$

dA , is one of the cylindrical surface, where $\beta = \cos\tan t$, then:

$$dA = \hat{a}_\beta a(\cosh\beta + \cos\alpha)^{-1} d\alpha \tag{12}$$

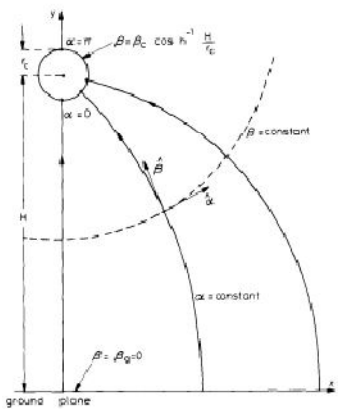


Fig.3.Bipolar co-ordination in conductor to plane configuration

Where $\hat{a}_\beta$ is a unit vector in the β co-ordinate direction.

Because the electric field is assumed to have the same direction as that of the space-charge-free field (Deutsch assumption), the integration of space charges for updating them was performed along $\hat{a}_\beta$ direction. The space charge densities located at nodes (i, 1), around the periphery of the conductor is assumed initially as:

$$\rho_{i,1} = \rho_e \cos(\frac{\theta_i}{2}), i = 1,2,...M \qquad (13)$$

Where M is the total field lines (was equal to 30 in this work) and ρ_e is the value of $\rho_{i,1}$ at $\theta = 0$;

The value of ρ_e was estimated using an approximate expression reported before [10] for the charge density at the ground plane:

$$\rho_e = \frac{E_g H}{E_{crit} R} 4\varepsilon_0 \frac{V_0(V - V_0)}{H^2 V(5 - 4\frac{V_0}{V})} \qquad (14)$$

Where E_g the space charge free electric field at the ground plane is, E_{crit} is determined by analysis of model in each step in ANSYS and V_0 is the onset voltage.
Using (1-4) the (15) can be obtained as:

$$\nabla\rho \cdot \nabla\Phi = \frac{\rho^2}{\varepsilon_0} \qquad (15)$$

Substituting (4) into 15 ,one obtain (16)

$$\frac{\partial \rho}{\partial l}\hat{u}_l = -\rho^2 / E\varepsilon_0 = h(\rho, l)$$

Starting at conductor's surface, (16) is integrated along each lines to estimate the nodal space-charge densities. For the first step ρ is determined by (13), and initial value of E, is E_{crit}.
This estimate of the space charge density is utilized to determine the distributed space charges at the FE mesh nodes.
By (16) using Rung-Kutta method the value of $\rho(l + \Delta l)$ was estimated.

The previous steps to calculate $\rho(l + 2\Delta l)$ and $\rho(l + 3\Delta l)$, … was performed to estimate the space charge densities at all nodes in each integration nodes.

The two previous steps was performed for all integration routes (M=30) to identify the space charges at all nodes around the conductor.

In Rung-Kutta integration method, the Simpson method is used. In each step of integration for calculation $\rho(l + \Delta l)$, the four parameters K (i=1 ,..,4) were used to determine it. For calculation $\rho(l + \Delta l)$ along electric field by transferring bipolar co-ordinates to Cartesian co-ordinates with (8-10) the (17) is used:

$$\rho_{i+1} = \rho_i + \frac{\Delta l}{6}[K1 + 2K2 + 2K3 + K4) \qquad (17)$$

Where K1 to K4 is determined from (18-21) [10]:

$$K1 = h(\rho_i, l_i) \qquad (18)$$

$$K2 = h(\rho_i + \frac{K1}{2}, l_i + \frac{\Delta l}{2}) \qquad (19)$$

$$K3 = h(\rho_i + \frac{K2}{2}, l_i + \frac{\Delta l}{2}) \qquad (20)$$

$$K4 = h(\rho_i + K3, l_i + \frac{\Delta l}{2}) \qquad (21)$$

After calculation $\rho(l + \Delta l)$, the process were repeated to evaluate $\rho(l + 2\Delta l)$,…

D- Estimation Electric field and Potentials

In this step the estimated space charges in previous step were applied to model in ANSYS software to calculate the potentials and electric fields in all nodes.

These values of potentials and electric fields were used in next step of updating space charges.

E- Space Charge densities correction

The last two estimated of potentials at each node, $\Phi^{(l)}, \Phi^{(l+1)}$ are compared. Nodal potentials error E_v relative to the average value of nodal potential Φ_{av} is defined as:

$$E_v = \frac{\left|\Phi^{l} - \Phi^{l+1}\right|}{\Phi_{av}} \tag{22}$$

Where

$$\Phi_{av} = \frac{\left|\Phi^{l} + \Phi^{l+1}\right|}{2} \tag{23}$$

If the maximum nodal potential error exceeds a prespcifeid error δ_1, a correction of $\rho_{i,N}$ which is the space charge density at the last node of each field line, was made. The correction follows by (24),

$$\rho_{i,Nnew} = \rho_{i,Nold}[1 + f \max\{E_v\}] \tag{24}$$

Where f is an acceleration factor, take equal to 0.5.

F- Converge condition

The steps 3-5 repeated until the maximum error in calculation of potential become less than a prespcifeid error δ_2.

G- Calculation of corona current

I. without considering ion diffusion

For each applied voltage above the onset value, corona current is equal to the sum of current flowing, i.e.

$$I = \sum_{i=1}^{M} J_i A_{i,1} \tag{25}$$

As:

$$J = k\rho E \tag{26}$$

Then:

$$I = k(\rho_{1,1}E_{1,1}A_{1,1} + \ldots \rho_{M,1}E_{M,1}A_{M,1}) \tag{27}$$

II. Considering Ion Diffusion as constant value

In this case, the ion diffusion is constant and the variation of electrical charges as function of constant parameter D and electrical field are updating to converge.

$$D = cte. = m \qquad cm^2/s \tag{28}$$

$$\vec{J} = k\rho\vec{E} - D\frac{\partial \rho}{\partial l} \tag{29}$$

$$\frac{\partial \rho}{\partial l} = \frac{1}{D}(k\rho\vec{E} - \vec{J}) \tag{30}$$

$$\frac{d\rho}{dl}\hat{a}_l = \frac{1}{D}(k \cdot \rho(l + \Delta l) \cdot E(l + \Delta l) - J(l)) \tag{31}$$

III. Considering Ion Diffusion as function of electrical field intensity

When the diffusion ions considered by (32) as function of electric field E, ion draft velocity, υ relative air density , δ ,[12]then in step of updating space charges ,instead of (16) ,(35) must to be solved.

$$D = [\upsilon / E] \\ [0.3341 \times 10^9 \times (E'/\delta)^{0.54069}] \quad cm^2/s \tag{32}$$

In this step, based on upgrading parameters, the value of ion diffusion as function of electrical intensity as mentioned in Equation (32) is calculated and so used in equation (35).

$$\vec{J} = k\rho\vec{E} - D\frac{\partial\rho}{\partial l} \quad (33)$$

$$\frac{\partial\rho}{\partial l} = \frac{1}{D}(k\rho\vec{E} - \vec{J}) \quad (34)$$

$$\frac{d\rho}{dl}\hat{a}_l = \frac{1}{D}(k \cdot \rho(l+\Delta l) \cdot E(l+\Delta l) - J(l)) \quad (35)$$

In this state the corona current can be calculated as under expression:

$$I = k\sum_{i=1}^{M}\rho_{i,1}E_{i,1}A_{i,1} - D\sum_{i=1}^{M}\frac{\rho_{i,1}-\rho_{i,2}}{\Delta r_i} \quad 36$$

For solving above equations, two software's including MATLAB and ANSYS are implemented .this hybrid method is presented in [13, 14].

VI. RESULT AND DISCUSSION

In order to investigate the effect of how consideration ion diffusion on estimation power corona loss, two conductors to plane configuration as transmission lines in studying transmission loss [15-17]. A sample of grid for one investigated configuration is shown in Fig2.

The number of element is 703 with 1445 unknown nodal potentials. Before, investigation the effect of ion diffusion on calculation, at first in order to show the accuracy of last proposed method with this author , already presented and published in [14, 15],V-I characteristics of this configuration for present method by and previous method [5] as well experimental result are shown in Fig.4.

The specifications of studied conductor are: height H=0.495 m, Radius R=0.00165 m and surface factor $\eta = 1$.

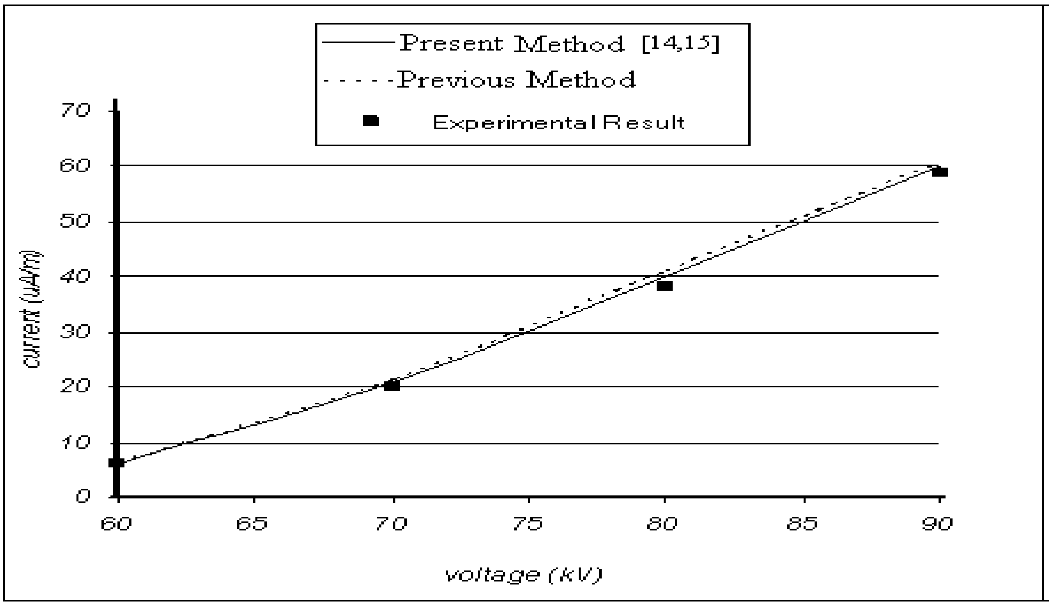


Fig.4.Peresent and previous calculated V-I characteristics of a conductor to plane configuration in comparison with that obtained experimentally

It is clearly that obtained results with proposed method by these authors, already published in [14, 15] is closer to the experimentally values and those obtained by previous method.

In Fig.5 the effects of the diffusion coefficient is shown.

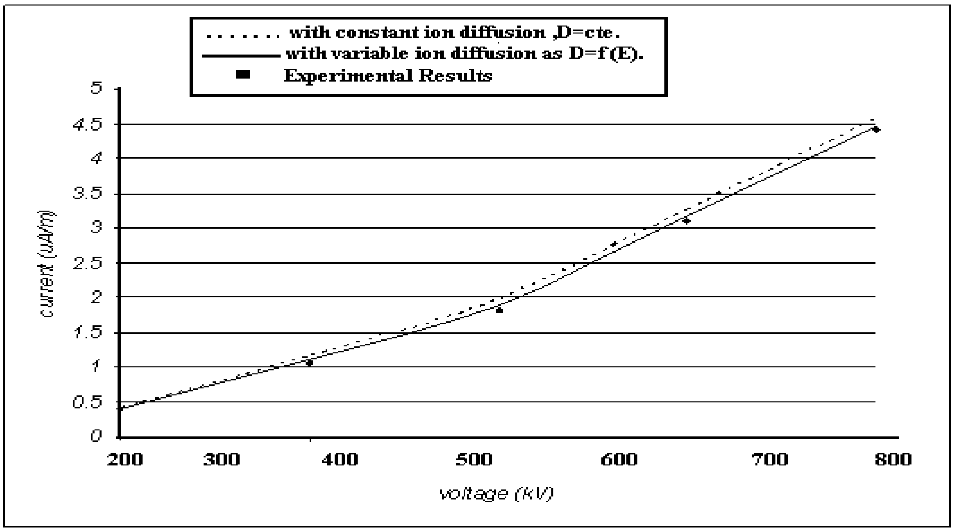


Fig.5.Calculated V-I characteristics of a conductor to plane configuration with and without considering ion diffusion in comparison with that obtained experimentally

This figure shows that, results value when considering ion diffusion as function of electrical field intensity is close to experimental value.

For this case study for various applied voltage, the differences between results of this assumption for ion diffusion with experimental value, is shown as histogram in Fig.6.

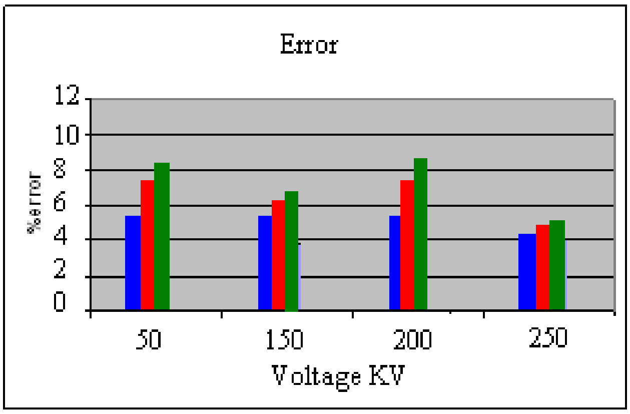


Fig.6. Mismatch between proposed method and experimental value

The maximum mismatch between experimental results and not considering ion diffusion in calculating corona power loss is 8.5 %.when considering ion diffusion as constant value, this accurate is 7.3% and when considering ion diffusion as function of electrical field, this accurate is 4.55% which shows the accuracy and persistence of considering ion diffusion as variable value and function of electrical field intensity as equation (32) considered in this study.

To investigate the result of this assumption for ion diffusion for full scale model a real transmission line is analyzed. The specifications of studied full scale line is height H=9.35m, radios R=0.1020m and surface factor $\eta = 0.75$

It is worth mentioning that when ion diffusion D as defined by (28) is considered and used in calculation, the number of iterations was increased; however the number of iteration in two state, without D calculation, and with D as constant value is less than state with considering it as function of electrical field.

The numbers of iteration for convergence for two case studies are reported in Table I.

TABLE I

TOTOAL NUMBER OF ITERATION FOR CONVERGENCE

With considering ion diffusion As function of Electrical Intensity	With considering ion diffusion As constant parameter	Without considering ion diffusion	Configuration
10	8	6	R=0.00165 H=0.495
17	12	10	R=0.0102 H=9.35

The applied voltage in this state is 120 kV.
The variation of electric field on ground plane with considering ion diffusion as three states was shown in Fig.7.

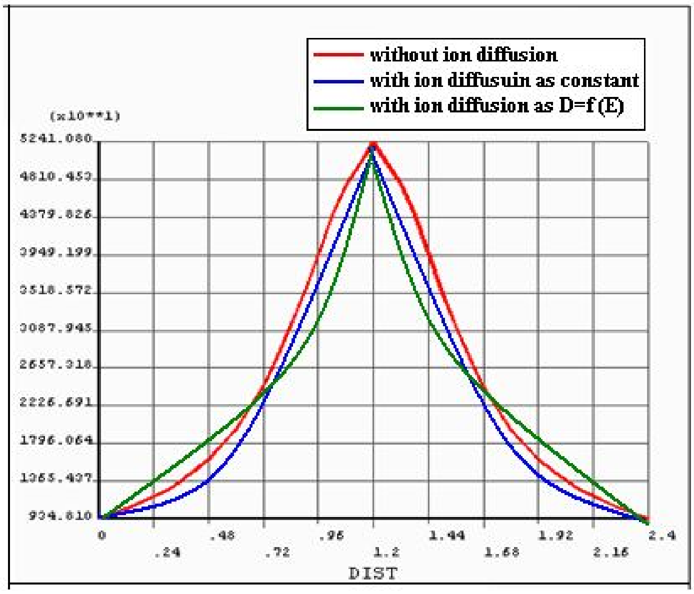
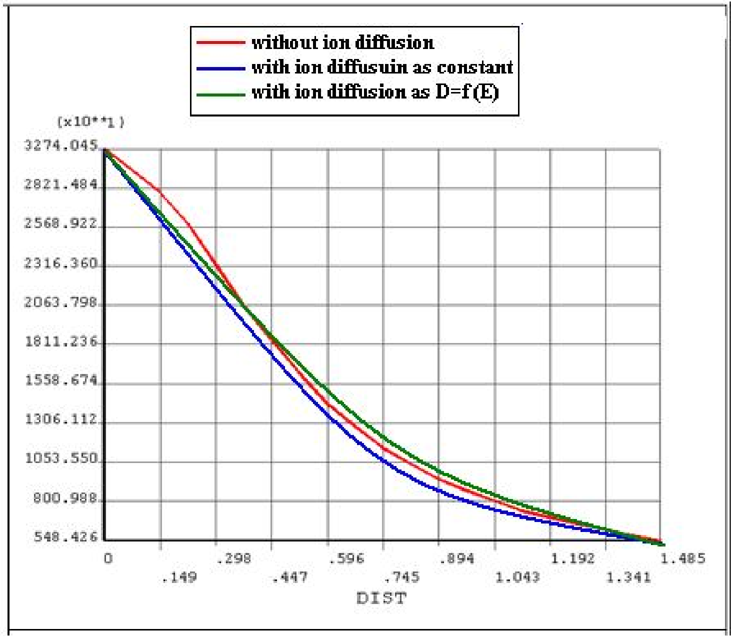


Fig 7.Distribution of electric field on ground plane

To investigate the effect of considering ion diffusion and how it's consideration on corona loss calculation, the characteristic of electric field on ground plane with this method and experimental values is shown in Fig.8.



Figs 8.Distribution of electric field on ground plane at right hand of conductor for applied voltage equal to 120 kV.

VII. Conclusion

In this paper, a new method has been presented with this author published already in [14, 15] has been applied to investigate the effect of ion diffusion on corona power loss calculation in transmission lines.

Calculations using MATLAB and ANSYS, detect that more accurate results are obtained when ion diffusion is considered as function of electrical field. Of course considering ion diffusion as function of electrical field intensity, leads to increase number of iteration.

In this paper two configurations as R=0.00165,H=0.495 and R=0.0102, H=9.3 are considered and results of simulation are presented and discussed.

REFERENCES

[1] M.Abdel-Salam and S.Abdel-Sattar ,Calculation of Corona V-I Characteristics of Mono polar Bundles using the Charge Simulation Method, IEEE,1989

[2] A. Mehrdad Jafarboland, Abdolamir Nekoubin, Finite-Element Analysis of Permanent Magnets Structure and Switching Angle Effects on the Efficiency of Two-Phase Brushless DC Motor, 2010 Praise Worthy Prize S.r.l, International Review of Electrical Engineering (IREE). Vol. 5 N. 5, September-Octobe, 2010 , Part A,pp.2013-2021.

[3] M.ZYu and E.Kuffel , A New Algoritm for Evaluating the Fields Associated HVDC Power Transmission Lines in the Presence of Corona and Strong Wind,IEEE Transactions on Magnetics ,Vol.29,No.2,March 1993

[4] M. Abdel-Salam, M. Farghally, and S. Abdel-Sattar, Finite element solution of monopolar corona equation, IEEE Trans. Dielect. Elect. Insul., vol. 18, pp. 110–119, Apr. 1983.

[5] Chung-Ming Yang, Neng-Yi Chu, Liang-Rui Chen, Wun-Chin Wu; Design of High Efficiency Wind Power ConverterBased on Duty Boundary Condition; Praise Worthy Prize S.r.l, , International Review of Electrical Engineering ,(IREE), Vol. 6. n. 1, February, 2011, pp. 117-122.

[6] Wijono, H Arof, WNLW Mahadi, SM Said, Finite Element Analysis of Axial, Radial and Halbach Permanent Magnet Linear Generators, Praise Worthy Prize S.r.l, , International Review of Electrical Engineering ,(IREE), Vol. 5. n. 6, Decembe, 2010,Part A, pp. 2623-2629.

[7] Alenka Milovanovic, Branko Koprivica, Miroslav Bjekic, Application of the Charge Simulation Method to the Calculation of the Characteristic Parameters of Printed Transmission Lines; , Praise Worthy Prize S.r.l, , International Review of Electrical Engineering ,(IREE), Vol. 5. n. 6, Decembe, 2010, Part A,pp. 2722-2726.

[8] Aboelsaad, M.M.; Shafai, L.; Rashwan, M. Numerical assessment of unipolar corona ionised field quantities using the finite-element method (HVDC transmission lines), Science, Measurement and Technology, IEE Proceedings

[9] M.Abdel-Salam and Z.Al.Hamouz, ,Novel finite-element analysis of space-charge modified fields,IEEE Transactions on Magnetics, Vol.41,No.5,September 1994

[10] M.P.Sarma and W.Janischewsky, Analyis of corona losses on dc transmission lines. Pt. I-Unipolar lines,IEEETrans.Power

[11] M. Horestine, Computation of corona space charge, electric field, and V–I characteristics using equipotential charge shells, IEEE Trans. Ind. Applicat., vol. 20, pp. 1607–1612, Nov./Dec. 1984.

App.Syst. vol.88,pp.713-731,1969

[12] M.M.Aboelsaad,L.Shfai and M.M.Rashwan , Improved analytical method for computing unipolar Dc coroa losses, IEEE Proc,Vol.136,Pt.A,No.1,JANURY 1989.

[13] M.Mohammadi, R.Ebrahimi and M.Najafi, 2011, "New Approach for Corona Loss Calculation Considering Ion Diffusion Variation Using FEM", International Review of Electrical Engineering (I.R.E.E.), Vol. 6, n. 2, Mrach-April

[14] M. Mohammadi, R. Ebrahimi, 2011," Corona Losses Calculation in HVAC Transmission Lines Using FEM and Comparison with HVDC Corona Losses", Australian Journal of Basic and Applied Sciences, 5(5): 833-843, 2011

[15] M.Abdel-Salam,M.Faghally,S.Abdel-Sattar,D.Shamloul, Analysis of ac Corona Power Loss for Single Phase Transmission Lines,Intern.Symposium on Gaseous Dielectrics,Knoxville,pp.492-497,1984.

[16] W.L.Lloyd,Jr.and E.c.Satarr, Methods Used in Investigating Corona Loss by Means of cathode Ray Oscillogrsph,AIEE Trans,Vol.26,pp.997-1008,1927.

[17] M. Y. Hassan, M. A. Almaktar, M. P. Abdullah, F. Hussin, M. S. Majid, H. A. Rahman, The Impact of Transmission Loss Component on Transmission Cost Recovery in Pool Electricity Markets, 2010 Praise Worthy Prize S.r.l, , International Review of Electrical Engineering ,(IREE), Vol. 5. n. 4, August 2010, pp. 1736-1746.