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Analysis of Parameters Affecting the Capacitive Interference between Pipelines and Power Overhead Line Using Genetic Algorithms

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Abstract: The proximity to high voltage power lines and gas pipelines is sometimes unavoidable for space reasons density of the soil. These pipelines are subject to electrical interference generated by power lines under normal and fault conditions. Due to this interference, AC voltages and currents can be induced on the aerial metallic pipeline, which may present a risk of electric shock to the operator; also threaten the integrity of the pipeline equipment. This paper aims to examine the capacitive coupling and the various factors affecting the level of this coupling, using a combination of charge simulation method and genetic algorithms (GAs) for the optimal position and number of fictitious charges used in CSM. The simulation results are compared with those obtained from the impedance matrix, a good agreement has been obtained.

Keywords: Charge Simulation Method (CSM) ,Optimization, Genetic Algorithm (GAs) , Capacitive Coupling , HV Power Lines, Aerial Pipeline

1. Introduction

Industrialization and population increase in the country have led to growing electricity needs. The high and very high voltage transmission lines are used to transmit this electricity over long distances, at this high voltage, the power lines produce high electric and magnetic fields in their own corridors [1,2], which can induce voltages on an aerial metallic pipeline that run parallel to power lines under steady state and fault conditions. This electrical interference may present a risk of electric shock to the operators, the corrosion of the steel and the perforation of the pipeline coating. It can also damage the cathodic protection equipment [3-6]. However, for personnel safety reasons, it is very interesting to evaluate the capacitive coupling and the factors affecting, for the capacitive coupling simulation and modeling in high voltage systems,the charge simulation method, due to its favorable characteristics, is very commonly used for the computation of electrostatic field intensity and potential analysis in HV systems [7,8].

The charge simulation method (CSM) due to its favorable characteristics is very commonly used successfully and accurately .This method is the most understandable one and it is relatively simple to program and accurate, this method gets approximate solution and has a little difference from actual situation. For the optimization problem, different evolutionary computation techniques have been used in recent years. Among them, the Genetic Algorithms (GAs) and evolutionary algorithms (EA) and particle swarm optimization (PSO).

The Genetic Algorithm (GAs) was introduced in the mid 1970 by John Holland and his colleagues and students at the University of Michigan. Genetic algorithm is a numerical technique used to find an approximate solution of optimization and the search for solutions to problems [9-12].

In this paper, a Genetic Algorithm (GAs) is used to find the best locations and optimal numbers of fictitious simulation charge, they are known for their ability to find the best solution from a set of possible solutions. The aim is also to examine the effect of different factors (pipeline's radius and position, arrangement of phases, earth cable, observation point, length of the parallel exposure) that affect the level of the capacitive coupling.

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2. Capacitive coupling

The capacitive coupling disturbance is produced by the electrostatic field of the HV transmission line by inducing electric charges in the metallic pipeline in close proximity. It needs to be evaluated for aerial pipeline that is electrically isolated from the earth. It is a form of running coupling across the capacitance between the AC transmission lines and the pipeline in series with the capacitance between the pipeline and the adjacent earth as shown in figure 1. For a buried pipeline, the capacitance between the pipeline and its surrounding earth is negligible, the earth acts as an electrostatic shield, the soil acts as an electrostatic shield that provides a shielding effect against the electric field. Adverse effects due to capacitive coupling mainly concerned the safety of operating personnel comes into contact with the metal pipeline [3, 13-15].

A*ccording to the circuit diagram* as shown in *figure* 1, the total induced voltage in the pipeline, from the power lines is given by the expression:

$$V_p = \frac{j.R.C_{12}.\omega}{1 + j.R.(C_{12}+C_2).\omega} V_L \tag{1}$$

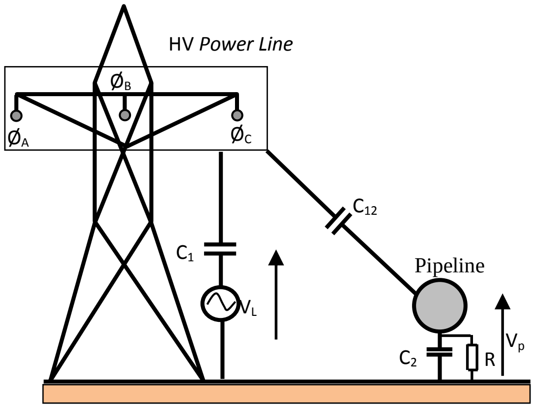

Figure 1. Capacitive coupling between pipeline and HV power line

3. Capacitive coupling calculation

The basic principle of operation is based on replacing the distributed charges on the surface of the conductor, with N fictitious line charges q_j inside the conductor [7,8,16-18].

Values of fictitious charges are determined by satisfying the boundary conditions at a number of contour points selected at the conductor surfaces. Once the values of fictitious charges are determined, the electrostatic potential and electric field at any point in the region outside the conductors can be calculated using the superposition principles according to the following *Equation* [19-22].

$$V_{c_i} = \sum_{j=1}^{N} p_{ij}\left(\vec{r}_{c_i}, \vec{r}_{q_j}\right) \cdot q_j \tag{2}$$

Where: P_{ij}: the potential coefficient related to the potential of the j^{th} charge at the i^{th} point, q_j : the simulation charge, N : the total number of fictitious charges (simulation charge).

If conductor charge and image are placed at a distance (y_i) and (- y_i) respectively from equipotential surface (V = 0), as shown in figure 2, the potential coefficient of a point (P) of this surface is given by:

$$p_{ij}\left(\vec{r}_{c_i}, \vec{r}_{q_j}\right) = \frac{1}{2\pi\varepsilon_0} Ln \frac{r'_{ij}}{r_{ij}} \tag{3}$$

Where: ε_0 : is the permittivity of free space (F/m); r_{ij} : the distance between conductors i and j; r'_{ij} the distance between conductor i and the image of conductor j.

$$r'_{ij} = \sqrt{(x_i - x_j)^2 + (y_i + y_j)^2}$$
$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{4}$$

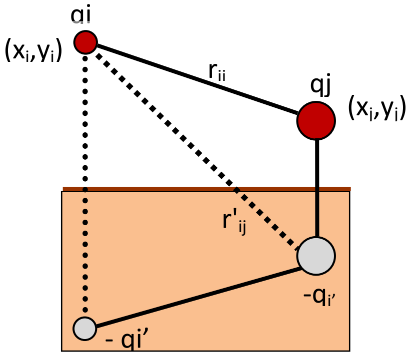

Figure 2. Determination of the potential coefficients for overhead lines

The arrangement of fictitious charges and contour points in the conductors of the line and the pipeline is shown in figure 3. The coordinates of these points are calculated using the following formulas [18,23,24].

$$\left.\begin{aligned} x_k &= x_0 + R.\cos(k\,\theta_k) \\ y_k &= y_0 + R.\sin(k\,\theta_k) \end{aligned}\right\} \tag{5}$$

Where: $R=r_1$ if k=i, r_2 if k=j; y_0: heights of conductors and pipeline above ground; x_0: horizontal coordinates of conductors and pipeline.

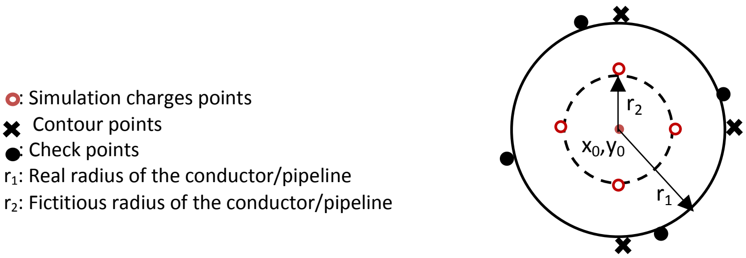

Figure 3. 2-D arrangement of simulation charges and contour points for the line (Conductor/ Pipeline)

After having determined the values of the fictitious charges, we must check both criteria: the number and position charges chosen by calculating the new potential V_{vi} that corresponds to the new verification points on the contour. Then, we must compare the new potential calculated and the real potential V_{ci}; the accuracy of this method is done by calculating the error ε. [24,25].

$$\varepsilon = \sum_{i=1}^{N} \left| \frac{V_{c_i} - V_{v_i}}{V_{c_i}} \right| .100 \tag{6}$$

The magnitude of the total electric field E_p at the desired point P (x_p, y_p) is calculated by the following equation [17, 24,25].

$$E_p(\vec{r}_p) = -\sum_{j=1}^{N}\left[\nabla p_{ij}\left(\vec{r}_p, \vec{r}_{q_j}\right)\right]\cdot q_j \tag{7}$$

The induced voltage V_p at any point P (x_p, y_p) due to the simulation charges q_j (x_j, y_j) can be obtained by using the theorem of superposition [24,26].

$$V_p(\vec{r}_p) = \sum_{j=1}^{N}\left[p_{pj}\left(\vec{r}_p, \vec{r}_{q_j}\right)\right]\cdot q_j \tag{8}$$

If a person touches an unearthed pipeline and thereby connects it to earth, the discharge current through the person is given by [24,26,27]:

$$I_p = C_p.\frac{dV_p(\vec{r}_p)}{dt} \tag{9}$$

Where: C_p – the pipeline's capacitance to earth per unit length is given by inverse the self-potential coefficient P_p of pipeline.

$$P_p = \frac{1}{2\pi\varepsilon_0}Ln\left[\frac{h_p}{r_p} + \sqrt{\left(\frac{h_p}{r_p}\right)^2 - 1}\right] \tag{10}$$

Where: h_p is the pipeline's height above ground from the pipe's centre and r_p is the pipeline's radius.

4. Genetic Algorithm (GAs)

The genetic algorithm is a stochastic optimization method chosen for its proven effectiveness in particular to solve nonlinear problems with very large spaces and solutions to many variables; the algorithm is based on the mechanism of natural selection and genetic. Its principle of operation is extremely simple. We start with a population of potential solutions arbitrarily chosen initials. We evaluate their relative performance. Based on this performance we create a new population of potential solutions using simple evolutionary operators: selection, crossover and mutation. This cycle is repeated until there is a satisfactory solution. In this case this optimization technique will be used coupled with the charge simulation method for a precise calculation of the electric field. The fitness function of the GAs employed to find the optimal values of these optimization parameters was evaluated using Equation (6) [20,28-30].

5. Admittance Matrix Method

To solve a problem of distribution of charges, it is more convenient to work with admittances. The admittance per unit length is given by the following equation.

$$\left.\begin{array}{l}[Y] = j.\omega.[P]^{-1} \\ [I] = [Y].[V]\end{array}\right\} \tag{11}$$

The resulting matrix of admittances for the three-phase system with the earth wires and metal pipeline is given by [3,27]:

$$\begin{bmatrix} I_c \\ I_p \\ I_g \end{bmatrix} = \begin{bmatrix} Y_c & Y_{cp} & Y_{cg} \\ Y_{pc} & Y_p & Y_{pg} \\ Y_{gc} & Y_{gp} & Y_g \end{bmatrix} . \begin{bmatrix} V_c \\ V_p \\ V_g \end{bmatrix} \quad (12)$$

Where: c, p and g represent respectively the phase conductors, pipelines and earth wires. The earthed earth wires are now eliminated by substituting $I_g = 0$ in *Equation* (12), giving:

$$\begin{bmatrix} I_c \\ I_p \end{bmatrix} = \begin{bmatrix} Y_c^{'} & Y_{cp}^{'} \\ Y_{pc}^{'} & Y_p^{'} \end{bmatrix} . \begin{bmatrix} V_c \\ V_p \end{bmatrix} \quad (13)$$

For an insulated pipeline, (I_p=0) and from *Equation* (13), the pipelines voltages to earth due to capacitive coupling with the power lines are given by:

$$\left[V_p\right] = -\left[Y_{pc}^{'}\right].\left[Y_p^{'}\right]^{-1}.\left[V_c\right] \quad (14)$$

Where: V_c are the known phase voltages to earth of the power lines.

In this study, we consider a transmission line of 275 kV (with a nominal frequency of 50 Hz) parallel with an aerial insulated pipeline, as shown in figure 4, the geometric dimensions of this circuit used ,are also shown in this figure. The length of the parallel exposure between the power transmission line and the pipeline is 4 km.

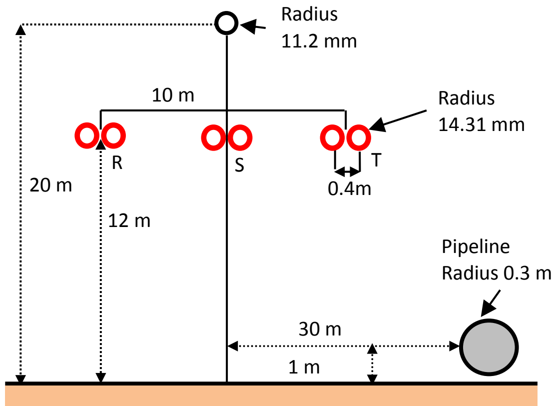

Figure 4. Single circuit horizontal configuration 275 kV with above pipeline

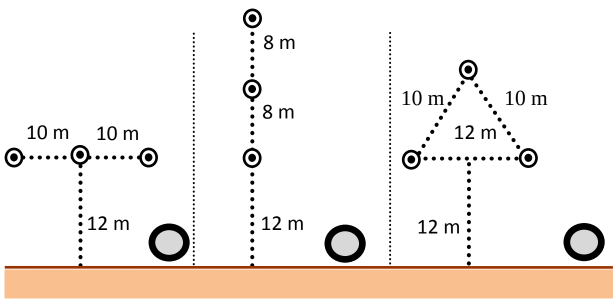

Figure 5. Different geometrical configurations for transmission overhead lines horizontal, (b) vertical, (c) delta

6. Results and Discussion

The charge simulation method parameters are first obtained by a genetic algorithm. We started by randomly generated population of 20 chromosomes. It generates 20 random values for the fictitious charges number and the fictitious radius. Each number of simulation charges (N) or fictitious radius (r) is converted to a 20-bit binary number. Each pair of parents with single point crossover generates four children. The crossover begins as each chromosome of any parent is divided into six parts, and the pair of parents interchanges their genetic material. After crossover there is a 1% probability of mutation. The parameters used in the numerical calculation are shown in Table 1.

Table 1. Charge Simulation Method and Genetic Algorithms Parameters

Method	Parameters
GA	number of optimization variables (6 variables) Population size N=20, Mutation probability Pm=1%, crossover probability Pc=0.9, Number of bits Nb=20, Number of generations 40.
CSM	Range of fictitious charges (n) 2–24 Range for rc (phase) 0.01–0.068 Range for rg (ground wire) 0.001–0.009 Range for rp (pipe) 0.1–0.27

The variation of the fitness function (FF) with number of iterations for this application is shown in figure 8. It illustrates the research process and optimization undertaken by the genetic algorithm. The simulation results for the number and location of simulation charges are shown in Figures 6 and 7, where it becomes clear that the algorithm converges quickly to these values, they are summarized in Table 2.

Table 2. The optimum values of the CSM

Conductor	Fictitious charges number	Fictitious radius [m]	FF
Phase conductor	3	0.0428255	2.1e -016
Ground wire	3	0.00892053	
Pipeline	18	0.120181	

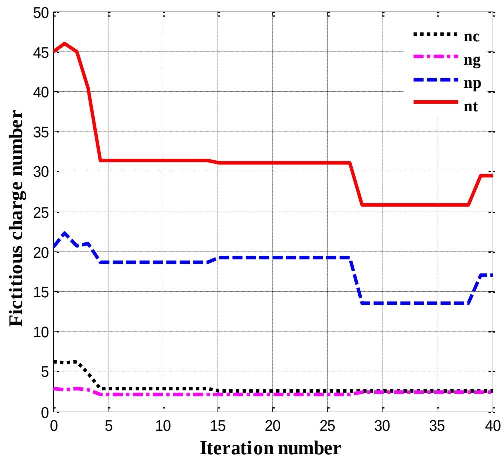

Figure 6. Convergence of the optimum values of fictitious charges number (n_c, n_g, n_p)

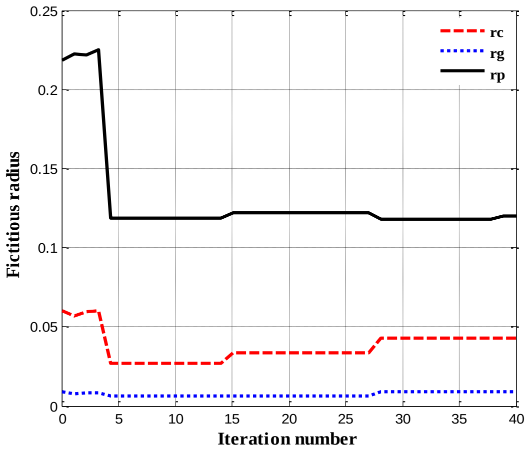

Figure 7. Convergence of the optimum values of fictitious charges radius (r_c, r_g, r_p)

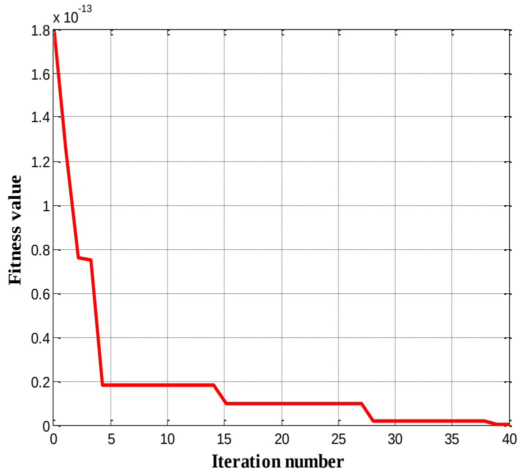

Figure 8. Variation of the fitness function with the generation number

Figure 9 shows the electric field distribution as a function of lateral distance (x) from the centre of the transmission line, at 1m height above the ground level with and without the presence of a metal pipeline, it is clear from the graph that the presence of the parallel pipeline in the vicinity of an overhead transmission line introduces a distortion of the electric field in the area of the location of the pipeline.The perturbed electric field Equations should reaches higher values on the pipeline surface than in the absence of this pipeline.

The perturbed electric field with and without the presence of a ground wire was calculated and is shown in figure 10. Ground wire does not carry the current; it is placed above the phase conductors. As can be seen from this figure, the presence of the ground wire causes a reduction of the electric field on the pipeline's surface which is equal to 21%, it expresses that the ground wire also serves to shield the electric field generated by the high voltage line.

The effect of varying the separation distance between the phase conductors and the pipeline is shown in figure 11. We can see that the electric field have lower value at the center of the line and increases to a maximum value E=8.91 kV/m for a separation distance equal to 12 m and then gets progressively reduced as one moves away from the center of the transmission line to achieve a negligible value to a point located very far from the line.

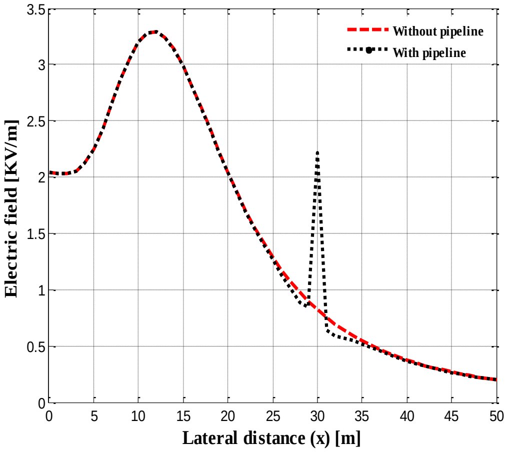

Figure 9. Electric field profile at 1 m above the ground with and without the pipeline

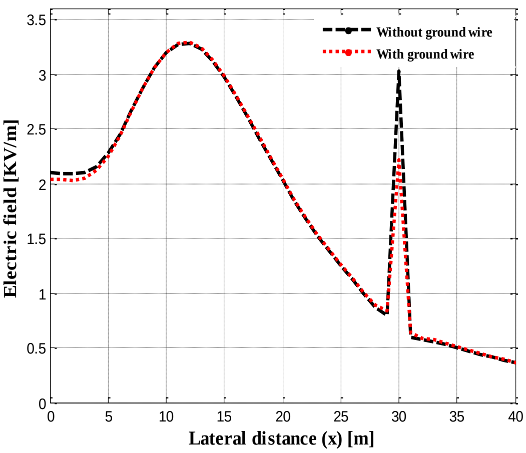

Figure 10. Electric field profile at 1 m above the ground with and without the ground wire

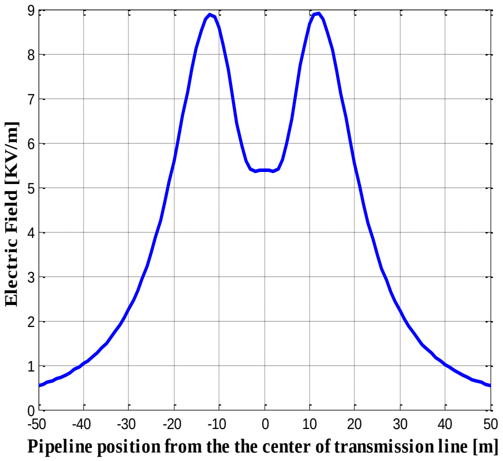

Figure 11. Perturbed electric field profile on the pipeline at 1 m above the the ground

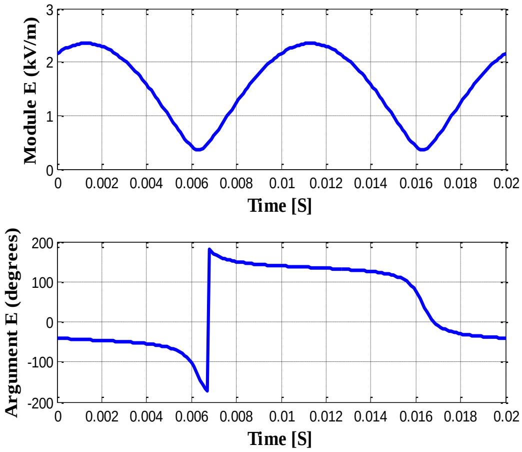

Figure 12. Temporal variation of the instantaneous value of the perturbed electric field

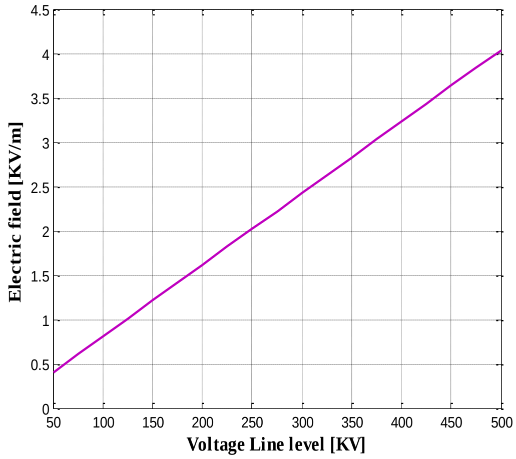

Figure 13. Variation of the perturbed electric field strength by varying the voltage level of transmission line

The module and the phase angle of the instantaneous electric field are shown in figure 12, for a time interval of [0- (1/ f)]. As shown in this figure, the peak value of electric field is obtained at instant t = 0.0013 s.

The intensity of electric field by varying the transmission line voltage has been computed and is shown in figure 13, as can be seen from this Figure this intensity is directly proportional to the transmission line voltage value that creates it. Higher the voltage level of transmission line, higher will be the perturbed electric field.

Figure 14 shows the electric field distribution on the pipeline surface at 1m above the ground level with different radius. The electric field strength at the pipeline's surface decreases as the radius increases, but indirectly proportional to the radius.

Figure 15 shows the electric field profile for different heights of the pipeline, as can be seen from this figure that the perturbed electric field level on the pipeline surface increases proportionally with the increase in its height.

The intensity of electric field by varying its calculation point from the ground surface (1 m to 12 m) at the location of the pipeline has been computed and is shown in Figure 16. The electric field strength decreases rapidly to a height of 3 m, and then decreases very slowly to reach a negligible value very far above the level of the line.

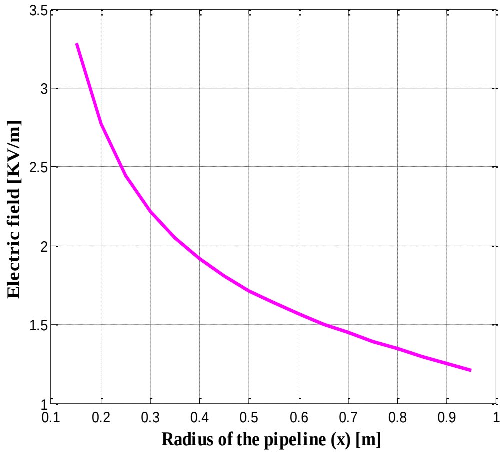

Figure 14. Variation of the electric field strength with pipeline radius

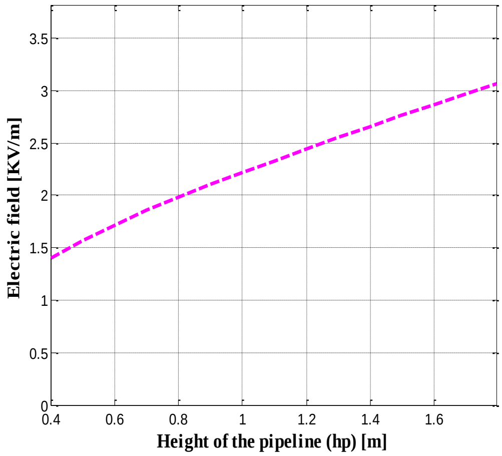

Figure 15. Variation of the perturbed electric field strength by varying the height of the pipeline above the ground

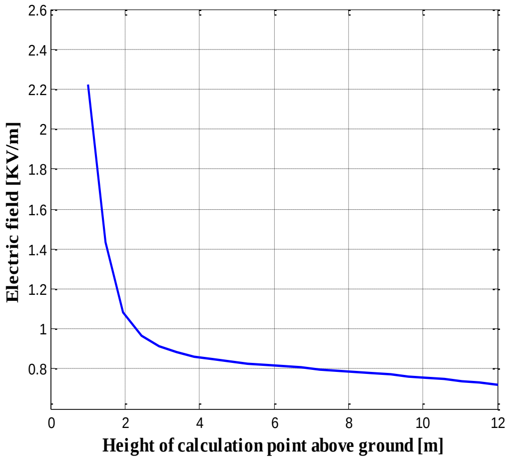

Figure 16. Variation of the perturbed electric field strength by varying the observation point above ground

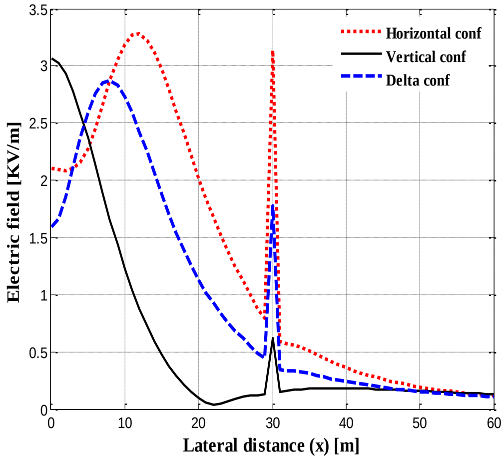

Figure 17. Lateral profiles of the perturbed electric field at 1m above the ground for various phase configurations

Figure 17 shows electric field profiles for three different phase patterns as shown in figure 5; flat, vertical, and equilateral delta, the height of the pipeline is 1 meter above the ground and is kept at 30 m from the midpoint of the line. It can be seen that the perturbed electric field at one meter height above the ground is lowest for the vertical configuration and highest for the flat configuration.

Figure 18 presents the evaluated induced voltage on the pipeline surface as a function of the horizontal proximity distance of pipeline. It is clear from the figure that the profile of induced voltage is broadly similar to that of the electric field. From the midpoint of the line, the induced voltage increases until it takes maximum value V= 3.26 kV for proximity distance equal to 12 m, and then decreases progressively with the proximity distance to negligible value at about 80 meters from the midpoint of the transmission line. It is recommended that the pipeline should be set up at a distance of nearby called critical distance where the induced voltage is almost zero.

Figure 19 shows the transverse induced voltage with the length of parallelism. It is clear from the figure.that the induced voltage level does not depend on the pipeline length exposed to the transmission line.

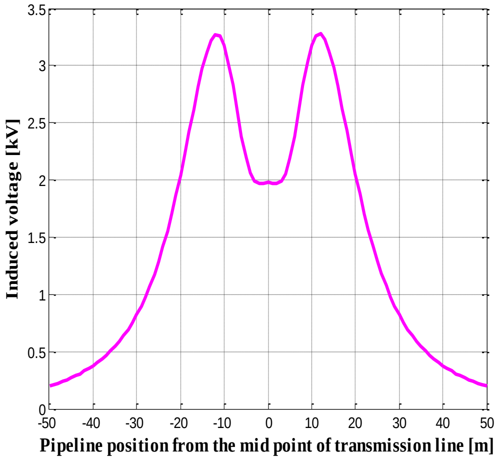

Figure 18. Induced voltage on the insulated pipeline due to 275 kV transmission line

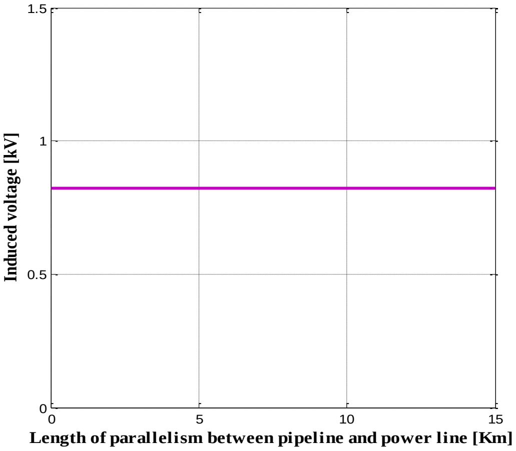

Figure 19. Relation between induced voltage and the length of parallelism between HV line and pipeline

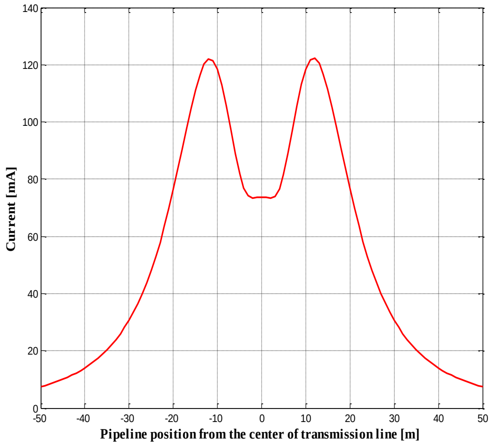

Figure 20. Discharge current profile passing through the human body

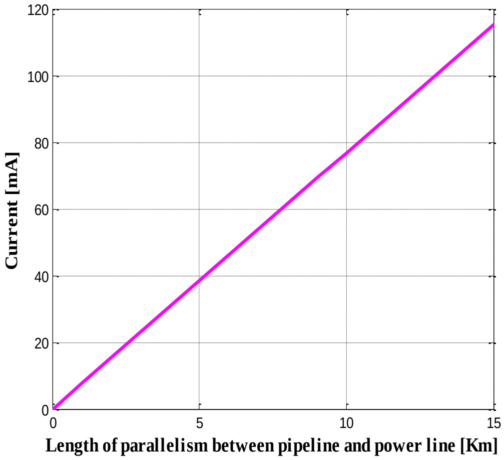

Figure 21. Relation between discharge current and the length of parallelism between HV line and pipeline

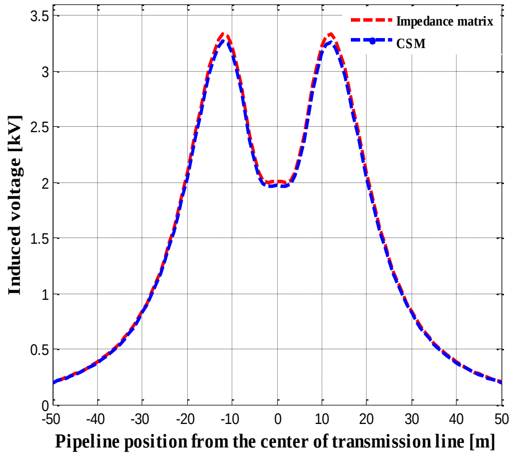

Figure 22. Comparison of induced voltage distribution between CSM+GA and the impedance matrix technique

According to figure 20 which shows the profile of the discharge current, we see that the variation of the current intensity along the pipeline is similar to that of the induced voltage, in this example the discharge current equal to 30.33 mA. Under steady state conditions, if a person touches a pipeline, a current higher than 10 mA would generally be considered unacceptable from personnel safety. Therefore, the pipeline would generally be earthed through an appropriate resistance.

The relation between the discharge current and the length of parallelism is shown in figure 21. For a parallelism between pipeline and HV line the current increases proportionally with the exposure length.

The last step is devoted to validate this modelling by comparing the simulation results obtained by the coupled (CSM +GAs) with those obtained by the matrix analysis method. In figure 22, we see a good agreement between the simulated induced voltages. This procedure ensures the effectiveness of the proposed method and to validate the simulation.

7. Conclusion

In this paper, we have used genetic algorithms (GAs) to determine the appropriate arrangement of the fictitious charges and contour points; the coupled (CSM +GAs) is proposed to estimate the electric field distribution and the effect of various factors on the capacitive coupling. The presence of the pipeline has a significant effect on the electric field strength, which corresponds to a considerable increase in the level of this field on the pipeline's surface due to external electrical charges accumulation. In flat configuration, with the increase of the separation distance, the electric field strength rises until it reaches a maximum, and then decreases rapidly.

The electric field intensity at the surface of the pipeline decreases as the radius of the pipeline increases. The presence of a ground wire in the circuit causes a slight reduction in the perturbed electric field at pipeline level.

In addition, other important factors can greatly affect the electric field at the pipeline's surface, such as, the pipeline's height above ground, the calculation point above the pipeline and the type of the transmission line configuration. The induced voltage in the aerial pipeline reduced with increasing the separation distance between the power line and the pipeline, but does not depend on the length of parallel exposure, it was noted by this calculation that the discharge current passing through a person in contact with the pipeline increases proportionally to the exposure length. The validation of the couples CSM is assured by the comparison between its results and those obtained by the matrix analysis method, the simulation shows a relative error of 3%, this error is considered relatively is very low.

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