International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

Comparative study of the effect of HVTL Electrostatic fields on gas pipelines using the ATP-LCC& CSM methods

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Abstract:

Overhead transmission lines require strips of land to be designed as right-of way (R.O.W). This R.O.W can also support other users besides the transmission lines such as pipelines, railways, etc. Increasing the amount of power transmitted requires higher voltages and currents, and therefore the transmission corridors are increased and in turn the competition for land and R.O.W increases.

Therefore, Analysis of electrical and magnetic interference effects of transmission lines upon nearby pipelines is very important due to the possible hazards resulting from the influence of electrical systems on pipelines such as safety of people making contact with the pipeline, damage to the pipeline and to the cathodic protection equipment.

In this paper, induced voltages on aboveground pipelines sharing the same right-of way (R.O.W) with high voltage transmission lines due to capacitive coupling were calculated. Two methods for calculations were used; the first is the ATP-LCC software which considers the sag of the transmission line in calculation, while the second is the charge simulation method, in which the transmission lines conductors are represented by infinite line charges. The two methods are applied to different realistic configurations of HVTL of different voltage levels including pipelines in their R.O.Ws. The effect of different pipeline design parameters such as pipeline diameter and its height above ground on the induced voltage is studied.

A comparison between the two methods was carried out and the reason of the difference between the results was clarified.

Charging currents per unit length of the pipeline were calculated using ATP-LCC.

Introduction:

Electromagnetic field effects of high voltage power transmission lines upon nearby metal pipelines have been a major concern since the early 1960s. Recently the problem has become even more acute, due to the restrictions imposed on various utilities to use common corridors between transmission lines and pipelines, called right-of-ways (R.O.W). These restrictions are imposed by various environmental associations aiming to protect nature and wildlife. However, there exist situations where power lines and pipelines have to be laid in close distances for several kilometers.

In this case, the electromagnetic interference problem is present both during normal and fault operating conditions of the transmission lines.

One of the main concerns in sharing a corridor between pipelines and power transmission lines is the very high levels of electric and magnetic fields generated that can affect humans and animals by creating a potential electric shock hazard. Therefore safety considerations for operation and maintenance personnel on pipelines should be taken into account. Direct effects on the pipeline, e.g. corrosion, coating damage or even puncture, effects on the electrical or electronic devices used for cathodic protection, metering, monitoring and other type of equipment associated with the pipeline are also main concerns in the problem of electromagnetic interference on pipelines.

Influences of H.V. lines can result from three types of couplings: capacitive, inductive and conductive. Under fault conditions, the induced voltages on influenced pipelines can reach a magnitude between several hundred volts and a few kilovolts. In normal operation, influences are normally much lower.

In case where pipelines are buried under the ground, capacitive effect is negligible and only the inductive and conductive couplings are considered.

For above ground pipelines, conductive coupling is neglected and only the inductive and capacitive couplings are considered.

Many scientific organizations and research institutes have examined the problem of electromagnetic field effects of HV transmission lines on nearby pipelines and published various reports and papers. Carson [1] was the first to study this problem using his wide known formulae. Various other approximating formulae were introduced later [2-8].

Several years ago, A joint program of EPRI and AGA led to the development of a computer software package (ECCAPP) (Electromagnetic and Conductive Coupling Analysis from Power lines to Pipelines) [5-6].

More recently, the Finite- Element Method (FEM) [7-8] and the finite-difference method (FDM) [9] were used in order to calculate the induced voltages across points on a underground pipeline, running parallel to a faulted line, and remote earth.

Several researchers studied the capacitive interference between power lines and pipelines [10-14].

Mazen Abdel-Salam used the charge simulation method to calculate the induced voltage on fence wires and pipelines by AC transmission lines [15]. Hanafy M. Ismail [16] studied the effect of oil pipelines existence which may run in the corridor and parallel to the conductors of the TL on the electric-field distribution at and above the ground surface level. He successfully used The CSM to model the conductors of both

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the TL and pipelines. Different design parameters of pipelines were varied to study their effects on field distribution.

In the following study, induced voltages on aboveground pipelines, sharing the same R.O.W with high voltage transmission lines, due to the capacitive coupling are calculated. The analysis is conducted by using the ATP-LCC program and the CSM method and a comparison between the results are made.

The analysis is applied to cases where the power line is parallel to the pipeline and also to situations where non-parallel pipeline sections exist (oblique exposures).

Calculation methods:

-Induced voltages on pipelines due to electric field calculation techniques:

Method (1):

The typical method of calculating the induced voltages on pipelines is by the use of potential coefficients [17]. The self potential coefficient of a conductor is given by:

$$P_{ii} = 11.185 \times 10^{6} \ln\left(\frac{H_i}{r_i}\right) \quad (1)$$

The potential coefficient between any two conductors can be found by:

$$P_{ij} = 11.185 \times 10^{6} \ln\left(\frac{H_{ij}}{r_{ij}}\right) \quad (2)$$

Where,

H_i= The distance between conductor i and the image of i.

H_{ij}= The distance between conductor i and the image of j.

r_i= The radius of conductor i.

D_{ij}= The distance between conductors i and j. In case of a 3 phase transmission line parallel to a pipeline as shown in figure (1), the relation between the potential coefficient matrix and the induced voltages can be described mathematically as:

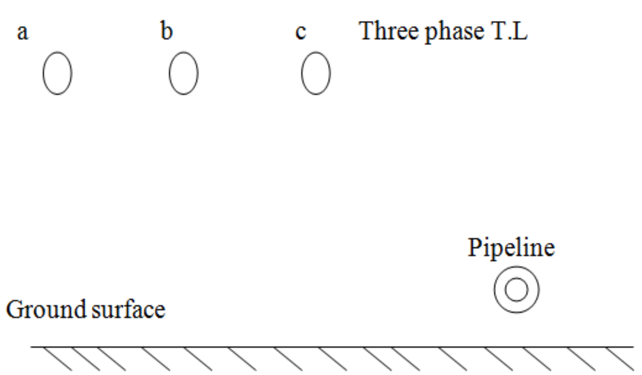

Fig.(1) Three phase transmission line parallel to a pipeline that is located above ground surface

$$\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_p \end{bmatrix} = \begin{bmatrix} P_{aa} & P_{ab} & P_{ac} & P_{ap} \\ P_{ba} & P_{bb} & P_{bc} & P_{bp} \\ P_{ca} & P_{cb} & P_{cc} & P_{cp} \\ P_{pa} & P_{pb} & P_{pc} & P_{pp} \end{bmatrix} \begin{bmatrix} Q_a \\ Q_b \\ Q_c \\ Q_p \end{bmatrix} \quad (3)$$

Where, Q_a, Q_b, Q_c, Q_p are the charges per unit length on phases a,b,c and the pipeline respectively.

By definition, charge is equal to the capacitance times the voltage or mathematically,

$$Q = CV \quad (4)$$

Stated another way,

$$[Q] = [P]^{-1}[V] \quad (5)$$

The reciprocal of potential coefficient is capacitance and vice versa.

Equation (3) provides a mean of determining the induced voltage on the pipeline where the steady state currents can be found as:

$$[I] = jw[C]\ [V] \quad (6)$$

Where : $[C]$ is the capacitance matrix per unit length (F/m).

If we consider the steady state current in the pipeline equals to zero then equation (6) can be expanded in the following form:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \\ 0 \end{bmatrix} = jw \begin{bmatrix} C_{aa} & C_{ab} & C_{ac} & C_{ap} \\ C_{ba} & C_{bb} & C_{bc} & C_{bp} \\ C_{ca} & C_{cb} & C_{cc} & C_{cp} \\ C_{pa} & C_{pb} & C_{pc} & C_{pp} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_p \end{bmatrix} \quad (7)$$

The induced voltage on the pipeline is calculated by the following equation:

$$0 = C_{pa} V_a + C_{pb} V_b + C_{pc} V_c + C_{pp} V_p \quad (8)$$

Therefore,

$$V_p = -\frac{1}{C_{pp}}\left(C_{pa} V_a + C_{pb} V_b + C_{pc} V_c\right) \quad (9)$$

Although the capacitances in equation (9) represent the capacitance per unit length, the induced voltage on the pipeline doesn't depend on the length of both the overhead T.L and the pipeline. This is mathematically true because the units of the capacitances (C_{pa}, C_{pb}, C_{pc}) and C_{pp} cancel.

The calculations of the capacitance matrix have been carried out using the ATP_LCC software which is used successfully for modeling and simulation of the systems under study, the terms of the capacitance matrix are then used in order to calculate the induced voltage on the pipeline using equation (9).

The value of the short circuit current $I_{s.c}$ per unit length from the pipeline to ground is simply determined by [15]:

$$\mathbf{I_{s.c} = \omega\, C_p\, V_p} \quad (10)$$

Method (2):

The charge simulation method (CSM) is applied to simulate the fields of the AC transmission lines. It consists of replacing the continuous charge distribution over the surfaces of the conductors by a discrete number of fictitious charges located inside the volume of the conductors. Another set of points called the contour points is chosen on the boundaries of the conductors.

Calculating the potential at the n contour points as functions of the unknown simulating charges and applying the complex boundary conditions leads to a system of linear equations which can be put in a matrix form as:

$$[V] = [P]\ [Q] \qquad (11)$$

By using a suitable numerical technique for solving this system of linear equations we can obtain the unknown simulating charges as:

$$[Q] = [P]^{-1}[V] \qquad (12)$$

After satisfying the solution quality measures, the simulating charges can be used to calculate the potentials and electric field stresses at any point in the region of interest. More details about the CSM with complex charges and complex boundary conditions can be found in the literature [10-11].

In this paper, the electric field and potential at any point in the region of interest can be calculated where the potential of the gas pipeline is not considered as zero voltage.

The above computer program is modified in order to read the potential coefficients between the high voltage transmission lines and the pipeline and the fact that the sum of the charges simulating the pipeline is equal to zero is utilized to solve the model and obtain the induced voltage on the pipeline and the unknown simulating charges.

This fact was used earlier by Mazen Abdel-Salam to calculate the induced voltages on fence wires and pipelines sharing the same R.O.W with AC power transmission lines [15].

Models under study:

Lateral profiles of the electric field for typical Egyptian 500, 220 and 132 kV high voltage transmission lines are presented and induced voltages on pipelines are calculated with varying the distance between the pipeline and the outer phase conductor of the transmission line.

The induced voltages on two pipelines running parallel to a 500 or 220 or 132 kV transmission lines are calculated, the separation between these two pipelines was taken one meter where the distance between the nearest pipeline and the outer phase of the transmission line is taken 10 meters.

Induced voltages on pipelines are calculated at different pipeline diameters and at different pipeline heights from ground surface and results were compared.

1-500 kV transmission line:

The model under study consists of a 500 kV three phase bundle conductors single circuit AC transmission line running parallel to a metallic gas pipeline or two metallic gas pipelines which are located at a height of 1m above ground surface. The diameter of each pipeline was taken equal to 100 cm.

The line phase conductors of the transmission line have a diameter of 30.6 mm each; there exists two earth wires of heavily galvanized steel conductor with a diameter of 11.2 mm each. The spacing between the sub-conductors in the bundle is 47 cm. The sag of the transmission line is equal to 12m.The geometric configuration of the model is shown in figure (2).

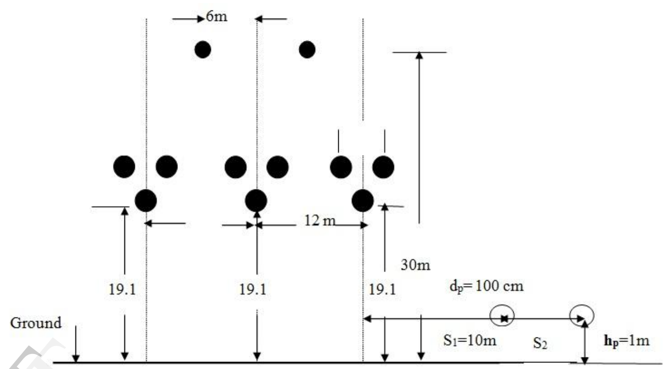

Fig.(2) Egyptian 500-kV transmission line arrangement running parallel to two pipelines at a separation distance of 10m between the nearest pipeline to the outer phase of the T.L and at a distance (S_2) between the two pipelines.

Results and discussion:

The separation distance between the pipeline and the outer phase conductor of the transmission line was varied (10, 20 and 50m) and the induced voltage on the pipeline due to the electrostatic field of the 500 kV transmission line was calculated using the ATP LCC Software, and also using the CSM. Fig.3 plots the induced voltage on the pipeline at different pipeline separation from the outer phase conductor.

The reason for the difference in results of the induced voltage between the two methods is that ATP-LCC Software considered the sag of the transmission line in calculation of the potential coefficients between the conductor and the pipeline or in the calculations of the capacitance matrix.

Whereas, in the CSM, the T.L phase conductors are modeled by fictitious infinite line charges that have height from the ground surface equal to the average of the heights of the nearest point to ground on the phase conductor (7.1 m) and the highest point of the conductor from the ground surface (19.1 m).in this case, the average height=13.1m.

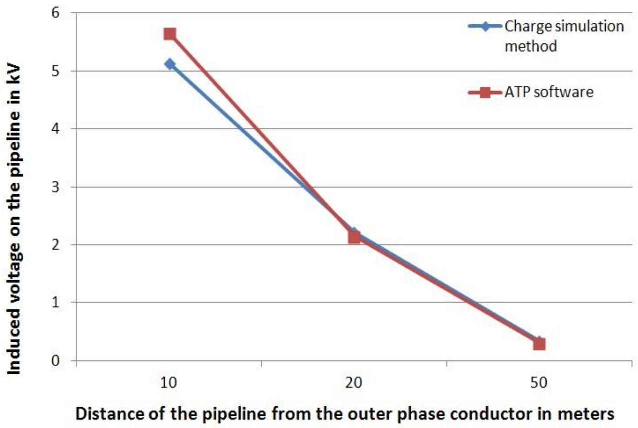

Fig.(3) Induced voltage on the pipeline due to 500 kV TL

2-220 and 132 kV transmission lines:

The model under study consists of a 220 kV three phase bundle conductors (or 132 kV three phase single conductors) double circuit AC transmission line running parallel to a metallic gas pipeline which is located at a height of 1m above ground surface. The diameter of the pipeline was taken equal to 60 cm for 220 kV transmission line cases and 100 cm for 132 kV transmission line cases.

For 220 kV, each phase has two conductors with diameter of 27 mm each; there exists one earth wire of heavily galvanized steel conductor with a diameter of 13.4 mm. The spacing between the sub-conductors in the bundle is 30 cm. The distance of outer phase from tower axis–center for each circuit is 4.1,4.4and 4.1m for phases A,B and C, respectively .The heights of the conductors from the ground surface are 15.7, 24.9, 35.1 m. The sag of the transmission line is equal to 8 m.

For 132 kV, each phase has one conductor with diameter of 27 mm; there exists one earth wire of heavily galvanized steel conductor with a diameter of 13.4 mm. The spacing between the sub-conductors in the bundle is 30 cm. The distance of outer phase from tower axis–center for each circuit is 5.4, 6.6 and 5.1m for phases A, B and C respectively .The heights of the conductors from the ground surface are 22.5, 26.1and 29.7 m. The sag of the transmission line is equal to 9.5m. The geometric configuration of the model is shown in figure (4).

Results and discussion:

The separation distance between the pipeline and the outer phase conductor of the transmission line was varied (10, 20 and 50m) and the induced voltages on the pipeline due to the electrostatic field were calculated using the ATP LCC Software, and also using the CSM, Figs 5 and 6 show the induced voltage on the pipeline at different pipeline separation from the outer phase conductor for 220 and 132 kV high reactance and low reactance arrangement transmission lines.

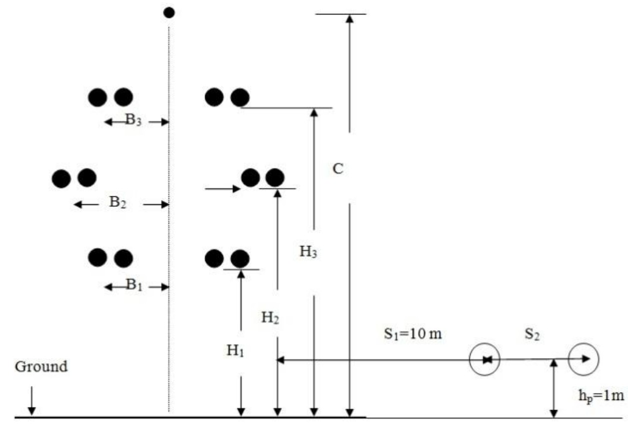

Fig.(4) 220 and 132 kV transmission lines used in Egypt running parallel to two pipelines at a separation distance equals to 10 m between the nearest pipeline to the outer phase of the transmission line

The reason for the difference in results of the induced voltage between the two methods is the same as in case of 500 kV transmission line. Results show that the induced voltage is lower in case of low reactance arrangement for the two voltage levels.

For 220 and 132 kV low reactance arrangement transmission lines, a special case was studied where the pipeline is located under the centre of the transmission line tower and the induced voltage on the pipeline was found to be zero by both the ATP-LCC software and also the CSM which is a good verification for both methods. This is due to the cancellation of the electrostatic fields created by both circuits of the double-circuit low reactance arrangement T.L where both circuits are separated from the pipeline by the same distance. This situation can be recommended in the erection of new pipelines in the right of way of double circuit low reactance arrangement transmission lines, as the induced voltages on the pipeline due to electrostatic fields will remain zero at normal operating conditions of the T.L. However, during fault conditions induced voltages may reach great values due to magnetic fields generated from the fault currents of the T.L.

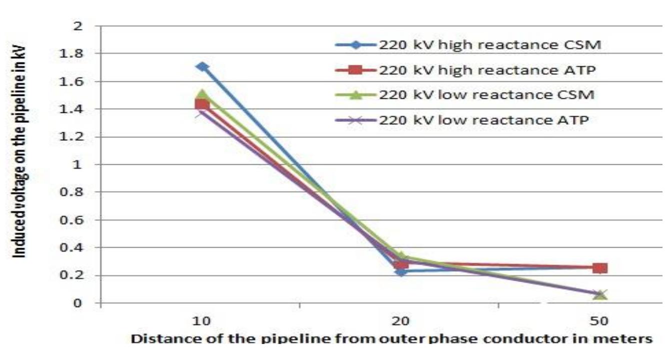

Fig.(5) Induced voltage on the pipeline due to 220 kV high reactance and low reactance transmission lines

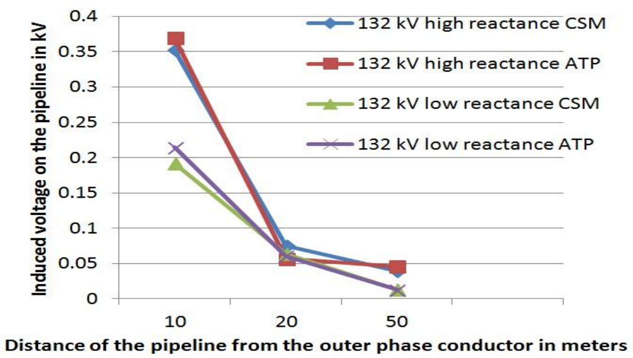

Fig.(6) Induced voltage on the pipeline due to 132 kV high reactance and low reactance transmission lines

-Induced voltages on two pipelines:

The induced voltage on two pipelines (with 1m separation distance) running parallel to a 500 or 220 or 132 KV T.Ls were computed with the separation distance between the nearest pipeline (P_1) and the outer phase conductor was varied (10, 20 and 50m). Results are shown in Table (1).

Results showed that the induced voltages on the nearest pipeline (P_1) haven't considerably changed from the case of single pipeline. These results are predicted to be changed in case the second pipeline (P_2) is grounded due to the disturbance created in electric field distribution near the grounded pipeline [16].

Table (1): Induced voltages on two pipelines running parallel to 500,220 and 132 kV transmission lines by using the ATP-LCC software:

Voltage level (kV)	Distance of the pipeline from the outer phase conductor (m)	Induced voltage on pipeline (P1)		Induced voltage on pipeline (P2)	
		P.U	kV	P.U	kV
500	10	0.014	5.66	0.011	4.63
	20	0.0058	2.37	0.0045	1.84
	50	0.0007	0.297	0.00065	0.26
220 kV (High reactance)	10	0.008	1.45	0.0065	1.18
	20	0.00151	0.27	0.00153	0.273
	50	0.00148	0.265	0.00149	0.266
220 kV (Low reactance)	10	0.0077	1.39	0.0065	1.176
	20	0.00175	0.31	0.00155	0.278
	50	0.00039	0.07	0.00037	0.067
132 kV (High reactance)	10	0.0034	0.37	0.0026	0.28
	20	0.0005	0.057	0.0003	0.033
	50	0.00044	0.047	0.00043	0.046
132 kV (Low reactance)	10	0.002	0.215	0.0016	0.172
	20	0.0005	0.057	0.0002	0.022
	50	0.00013	0.0144	0.00012	0.0126

Effect of changing the pipeline parameters on the induced voltage:

For 220 kV, low reactance arrangement T.L, the case of varying the pipeline diameter with keeping the height of the lowest point on the pipeline surface (h_p)(constant=0.5 m) was studied, Fig (7) clarifies the effect of varying the pipeline diameter on the induced voltage.

It was found that by increasing the pipeline diameter at constant h_p, the induced voltage considerably increases.

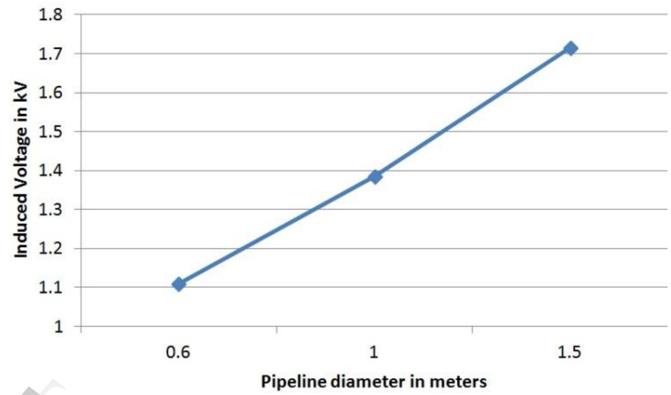

Fig.(7) Induced voltage on the pipeline at fixed height of the lower point = 0.5 m and different pipeline diameters for 220 kV low reactance arrangement

The case of varying the height (h_p) at constant pipeline diameter (d_p=1m) was also studied, Fig.(8) clarifies the effect of varying the height h on the induced voltage .

It was found that by increasing the height (h) at constant d_p, the induced voltage considerably increases.

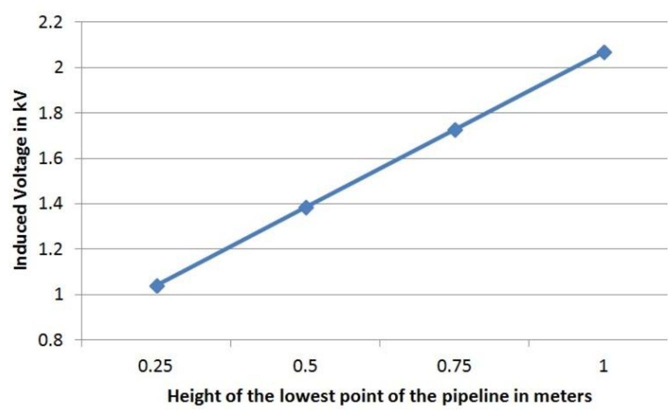

Fig.(8) Induced voltage on the pipeline at fixed pipeline diameter =1m and different heights of the lowest point for 220 kV low reactance arrangement

Short circuit charging currents to ground:

Mapping of electric flux lines for the transmission lines configurations under study shows that the flux lines from each phase conductor reaches the pipeline, the ground surface and the sky wires. Each phase conductor acts as a source or sink for its flux lines depending on the instantaneous value of the line-to-neutral voltages with time. This confirms that the pipeline has its own capacitance to ground and also has capacitance with each conductor. Part of the pipeline flux lines reach the ground plane depending on how large pipeline capacitance to ground relative to capacitances with transmission line's conductors. Unlike the induced voltage**,** the capacitance of the pipeline to ground and the charging current of the pipeline depend on the distance by which the pipeline runs parallel to the transmission line.

The capacitance to ground per unit length (F/m) C_p of the pipeline is calculated using ATP_LCC assuming that the pipeline is coated with a layer of polyethylene (0.1 m thickness and relative permittivity= 2.7) as an insulating material. The value of the short circuit current $I_{s.c}$ per unit length from the pipeline to ground is simply determined [15] by:

$$I_{s.c} = \omega C_p V_p$$

Table (2) lists the results of C_p and $I_{s.c}$.

Table (2): C_p and $I_{S.C}$ for different voltage levels

Voltage level	Distance of pipeline measured from outer phase conductor in meters (m)	Pipeline capacitance per unit length (F/m)	Charging current per unit length (mA/km)
500 kV	10	4.375e-11	776
	20	4.375e-11	295
	50	4.375e-11	41
220 kV high reactance arrangement	10	3.24E-11	148
	20	3.24E-11	27.4
	50	3.24E-11	26.6
220 kV low reactance arrangement	10	3.24E-11	141
	20	3.24E-11	31.9
	50	3.24E-11	6.96
132 kV high reactance arrangement	10	4.375E-11	50.8
	20	4.375E-11	7.82
	50	4.375E-11	6.35
132 kV low reactance arrangement	10	4.375E-11	29.5
	20	4.375E-11	8.34
	50	4.375E-11	1.78

Conclusion:

The effect of generated electrostatic fields from realistic OHTLs on nearby pipelines running parallel in their R.O.W has been studied using the ATP-LCC program and the CSM technique. It has been found that there is a small difference in results between the two methods due to the fact that ATP-LCC Software considers the sag of the transmission line in calculation of the potential coefficients between the conductor and the pipeline or in the calculations of the capacitance matrix. Whereas, in the CSM, The T.L phase conductors are modeled by fictitious infinite line charges that have height from the ground surface equal to the average of the heights of the nearest point to ground on the phase conductor and the highest point of the phase conductor from the ground surface.
For double circuit transmission lines, a comparison was done between the induced voltage results in case of low and high reactance arrangements of the T.L phase conductors; it was found that the induced voltage is lower in case of low reactance arrangement. In case of varying the pipeline diameter with keeping the height of the lowest point on the pipeline surface constant or varying the height of the lowest point on the pipeline surface at constant pipeline diameter the induced voltage considerably increases. Unlike the induced voltage**,** the capacitance of the pipeline to ground and the charging current of the pipeline depend on the distance by which the pipeline runs parallel to the transmission line. The capacitance of the pipeline to ground and the charging current of the pipeline also depend on the coating material relative permittivity, coating thickness and the radius of the pipeline.

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