Electromagnetic Interference between Electrical Power Lines and Neighboring Pipelines

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Electromagnetic Interference Between Electrical Power Lines and Neighboring Pipelines

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Abstract- Electromagnetic Field interference caused by electric power lines sharing the same corridor with pipelines can produce the unsafe operation of the protection and measuring systems of the pipeline under both normal and faulty conditions. Voltages can be induced on the pipelines from power lines in the areas where they run in parallel together. These voltages vary with the electrical characteristics and geometry of both systems. These voltages can affect the operating personnel, pipeline associated equipment, cathodic protection and the pipeline itself. Mitigation is required to reduce the voltage levels to limit that adverse effect for personnel and pipeline.

Keywords: AC interference, pipeline coating stress voltage, power line fault, electromagnetic interference (EMI), pipelines/transmission line interference, and right-of-way (ROW).

I. INTRODUCTION

Electromagnetic interference caused by electric transmission lines and distribution lines on neighboring metallic utilities, such as gas and oil pipelines became a major concern for design engineers. Recently when a pipeline runs more or less parallel to a high voltage power line for a significant distance, considerable voltage can be transferred to the pipeline under both normal power line operating conditions and short circuit conditions [1-2]. These voltages can represent an electrical shock hazard for personnel and the public .They can threaten the integrity of cathodic protection equipment, the pipeline coating, and the pipeline steel particularly during short circuit conditions.

This paper discusses an automated approach to analyze AC induced interference .All relevant parameters used for modeling the right-of-way are taken into account in computing the line parameter building the circuit model and automatically determining the maximum interference level between both two systems under steady state and fault conditions.

II. INDUCED VOLTAGE ON PIPELINES

One of the greatest causes of voltage induction on pipeline is line currents that flow in the conductors creating electromagnetic fields which always lie at right angle to the current that produce it [3].A time varying magnetic field will induce an electric field in any specified loop in its vicinity . Assuming a uniform magnetic field and a circular loop of radius r, the magnitude E of the electric field around the loop is:

$$E = \frac{dB}{dt} \times \frac{r}{2} \tag{1}$$

Where: $\frac{dB}{dt}$ is the rate of change of magnetic field. If the loop being considered is in a conducting medium of infinite extent, then a current of density J will be induced given by:

$$J = gE = g\frac{dB}{dt} \times \frac{r}{2} \tag{2}$$

Where: g is the medium conductivity. If a pipeline is close enough and parallel to the electrical transmission line the electromagnetic field will cut through the pipeline at right angle for a long parallel length and a voltage may be induced on the pipeline. In case of a symmetrical three phase AC transmission line the currents are equal in magnitude and 120 degrees apart as positive sequence, and the distances between conductors are equal the resultant induced voltages is equal to zero . When the system is unsymmetrical this will result in an AC potential along the pipeline.

The electric and magnetic fields under the transmission lines are complex functions of the conductors size, spacing and clearance from the flat grounding [4].The calculated electric and magnetic fields for over head lines having m conductors is:

$$E = \frac{1}{2\Pi\varepsilon_0}\sum_{n=1}^{m}\alpha$$

where:

$$\alpha = Qn\left[\frac{(X-x_n)X+(Y-y_n)Y}{(X-x_n)^2+(Y-y_n)^2}\right] - Q_n^*\left[\frac{(X-x_n)X+(Y+y_n)Y}{(X-x_n)^2+(Y+y_n)^2}\right] \tag{3}$$

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$$B = \frac{\mu_0}{2\Pi}\sum_{n=1}^{m}\beta$$

Where:

$$\beta = I_n\left[\frac{(Y-y_n)X+(X-x_n)Y}{(X-x_n)^2+(Y-y_n)^2}\right] - I_n^*\left[\frac{(Y-y_n)X+(X-x_n)Y}{(X-x_n)^2+(Y-y_n)^2}\right] \quad (4)$$

Where, Q_n : Charge on the conductor

$$Q_n^* = \left(\frac{\varepsilon-1}{\varepsilon+1}\right)Q_n \quad (5)$$

I_n : Current flowing in the n^{th} conductor

$$I_n^* = \left(\frac{1-\mu}{1+\mu}\right)I_n \quad (6)$$

ε : Relative permittivity of medium$=\varepsilon' - j\frac{1}{\rho w}$

ε' : Relative earth dielectric constant

ρ : Earth volume resistivity in ohm-m

μ_o: Earth and air permeability which is equal to $4\Pi \times 10^{-7}\ H/m.$

x_n, y_n : Conductor location w.r.t earth surface

X, Y : Unit vectors.

The magnitude of the induced voltage and current on the pipeline is a function of the following:

1- Physical geometry of separation between conductors, and conductors with pipeline.
2- The resistance of the pipeline coating.
3- The longitudinal resistance of the pipeline.
4- The length of the parallel path of power line and the pipeline.
5- Magnitude of electrical system current flowing.
6- Frequency of the electrical system.
7- Nature of the electrical system (single-phase or three phase).
8- Discontinuities where the pipeline diverts from the power line.

III. INTERFERENCE MECHANISM

The AC interference in a pipeline sharing a common corridor with a power line consists of an inductive component and conductive component. During normal conditions in the transmission line, only the inductive component is presented and the induced voltage will apply in the pipeline by the magnetic field generated by the power line. The conductive interference will apply in the pipeline when a fault occurs and discharge a large amount of current into the earth.

A Inductive interference

A pipeline and the electric of the power line circuit can exhibit significant mutual induction coupling due to long length of parallel path

$$M = K\left(L_t L_p\right)^{\frac{1}{2}} \quad (7)$$

Where: L_t transmission line inductance, Lp pipeline and associated equipment inductance, and K is the coefficient of coupling depending on the location (Ω/km).

If R is the resistance of earth and pipeline with its coating, then the current induced in the pipeline is:

$$I = \frac{M}{R}\frac{dI}{dt} = K\frac{\left(L_t L_p\right)^{\frac{1}{2}}}{R}\frac{dI}{dt} \quad (8)$$

The charge q that reaches the pipeline is therefore equal:

$$q = \int_0^{t_m} K\left(\frac{L_t L_p}{R}\right)^{\frac{1}{2}}\frac{di}{dt}dt = K\left(\frac{L_t L_p}{R}\right)^{\frac{1}{2}} I_m \quad (9)$$

Where, t_m is the time needed for current in conductor of T.L to reach its maximum value. I_m is peak current in conductors of T.L this level of interference is increased with decreasing the separation distance between the two systems, increasing soil resistivity and by increasing the magnitude of the flowing current in T.L. This may represent a possible direct electrical shock hazard and can affect the protection systems of the pipeline.

B Conductive interference

When a (SLG) fault occurs on a transmission line This may inject large amount of current into the soil during fault Conductive coupling with the near pipeline due to the currents flowing in the soil which is of particular concern of location where the pipeline is in close contact to the transmission line structures. This causes large and step voltages because the soil potential rise due to the large injected currents in its vicinity. If the pipeline coating has a high resistivity, the steel pipeline potential will remain relatively unaffected by the high potential of the surrounded soil .The difference of potential between the pipeline and the surrounded earth due to discharged current into the earth may be large enough to cause damage. The magnitude of the conductive current is a function of ground potential rise (GPR), separation distance and soil structures characteristic (e.g. multilayer or single layer, etc). Longitudinal induced voltage (V) between the two ends of the exposed section will be equal to[5] :

$$V = K \times I \times S \times C \quad (10)$$

Where: S=shared corridor length, (km), C=shielding factor (0 < C < 1)

IV. CORRIDOR

The corridor that has been analyzed is shared by a 3 bundle- 500kV three phase, single circuit, transmission line, in the west desert of Egypt as

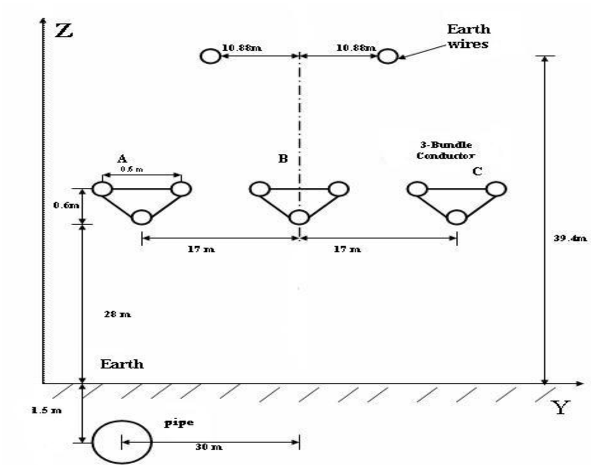

Figure 1: Power Tower Configuration

from Nubaria power station to Sidi-Krir power station with the length of 130 km,50 HZ, which is arranged in horizontal formation as shown in figure.(1) with separation distance of 17 m between conductors .The conductors are made from ACSR 495/65 mm2, each bundle phase consists of three inverted delta sub-conductors, the distance between the sub-conductors is 0.6m, the circuit has two earth wires, these wires are made of galvanized steel of size 108 mm2.The maximum phase current under normal conditions is 687A and 5000A at fault conditions. The power line is running in parallel with Sumed oil pipeline for a distance of 35 km. Sumed pipeline is made of coated steel, its outer diameter is 1.07m, wall thickness is13mm, the coating electric resistance is 100M Ω.m . The minimum spacing between pipeline and the power line is approximately 30m as shown in Fig. (2) and the the pipeline is buried 1.5m below the surface of the ground. It is expected that significant amount of induced AC volt would appear on the pipeline, especially during fault conditions.

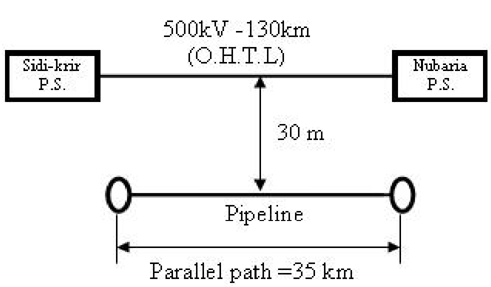

Figure 2: The Physical Layout of a Sumed Shared Corridor

V. COMPUTER MODELING

This study was developed using the computer program CDEGS (Current Distribution and Electromagnetic field, Grounding, and Soil structure) [5]. The computer modeling was used for analysis of electrical induction and conduction problems occurring in non-uniform three dimensional lossy environment (air and soil)when time harmonic currents are injected into various points of arbitrarily located conductors in that environment.

The computer modeling was developed to rapidly estimate the interference between pipeline and power line, calculating the induced voltage, longitudinal current on the pipeline and also to calculate the maximum electrical stress on the coating of the pipeline during normal and faulty conditions.

VI. INFLUENCE OF MITIGATION

Mitigation systems are designed to reduce induced currents, voltages and coating stress voltages to acceptable levels during power line load and fault conditions. In order to achieve a safe factor limit when the interference level is high, the computer model can be expanded to compute the effectiveness of different mitigation methods. The mitigation system has to be included in the computer model of the shared corridor. The interference study will be repeated for different separation distances between the power line and near by pipeline until mitigation objectives are met.

VII. METHODOLOGY

Interference levels due inductive and conductive coupling must be studied under normal load and fault conditions.

The maximum induced voltages on the pipeline must be calculated and the interference level should not exceed above 15 volt during normal load and 1000 volt during fault conditions according to national agency of corrosion engineering (NACE)[6]. The basic research methodology is given by the flowchart in figure (3).

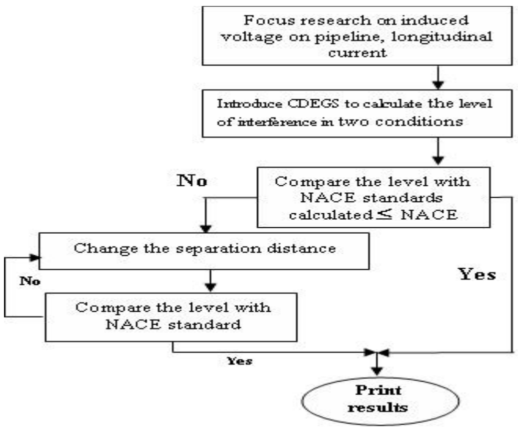

Figure 3: Flowchart of the Research Methodology

VIII. CASE STUDY

The prime objective of the work presented in this paper is to study the electrical interference taking place between power lines and pipeline in the parallel portion of 35 km between sumed oil pipeline and Nubaria/Sidi-Krir transmission line. Assuming that the pipeline and the power line are in the two dimensional plane y-z while the length along the x-axis. The origin of the pipeline (0,-1.5m) and the coordinates of the middle phase conductor is (30m, 28m)

A. Normal Condition

First, the complete interference study on the Sumed pipeline was carried out without any mitigation system; the computer module gives the steady pipe line potential. After counting this different reading, the mitigation method will be applied by changing the separation distance between the two systems from 30m to 1000 m and the curves for induced voltage, the longitudinal current and the maximum applied stress on coating is obtained.

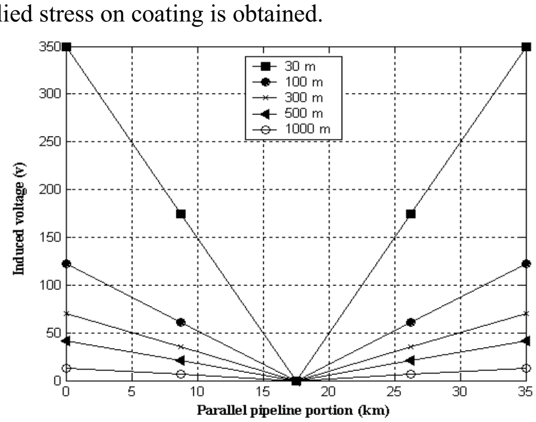

Figure 4: Induced Voltage on Pipeline at Different Separation Distance

Figure (4) presents the induced pipeline potential magnitude for this case. The curves are symmetrical around the mid point of the parallel path due to the symmetry of the power system. The maximum pipeline potential occurs at the ends of [7] the pipeline because of the strong discontinuity of the EMF at these two points forces a large leakage current from the pipeline. The minimum pipelines potential occurs at the midpoint of the pipeline because the induced EMF in the pipe on both sides of this point are the same, resulting in a minimum leakage current in the pipeline at this point. It is clear that the pipeline potential was reduced by increasing the separation distance. The maximum electrical stress on coating occurs on the ends of pipeline is the same way and equals to the maximum induced voltage on pipeline. The longitudinal current the maximum induced voltage on pipeline. The longitudinal current appears at its maximum values on the middle of the pipeline and decreases at both ends of the pipeline.

Table (1) gives the values of current at different separation distances between the two systems along the length of the parallel portion.

Parallel length (Km) / Separation distance (m)	0	8.75	17.5	26.25	35
	Induced current (A)				
30	0.875	0.897	0.905	0.897	0.875
100	0.304	0.310	0.314	0.310	0.304
300	0.173	0.177	0.179	0.177	0.173
500	0.1015	0.1035	0.1050	0.1035	0.1015
1000	0.0330	0.0336	0.0346	0.0336	0.0330

Table (1) : Induced Current (A) on Pipeline at Different Separation Distance

B. Fault Condition

The first step in any fault interference analysis should be the calculation of induced voltage levels on pipeline with no mitigation applied. The fault under consideration is a single line to ground fault (SLG). The pipeline potential (inductive and conductive) component, coating stress voltage and the longitudinal current on the pipeline are directly proportional to the magnitude of the fault current component The maximum fault current is 5000 A and assumed to be flowing from both sides of the fault location to the center of the corridor. Each curve shows induced pipeline potentials as a function of the common parallel distance between power line and pipeline. During a fault, inductive interference is presented well with a peak occurring at the fault location

B.1 Tower Shunt Current Magnitude

As shown in Fig (5) the maximum value of the tower shunt current magnitude is at the central location of the power line because the single line to ground fault is occurring in the center and decreases at both sides with increasing the distance far away from the fault location. The curve is symmetric due to the symmetry of the power system

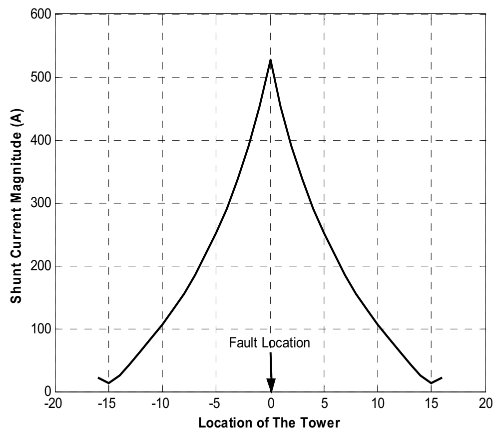

Figure 5: Tower Current Magnitude **with** Position

B.2 Tower Shunt Potential Magnitude

As shown in figure (6) it is obvious that this curve is similar in shape to the previous curve and the maximum shunt tower potential is occurring at the fault location.

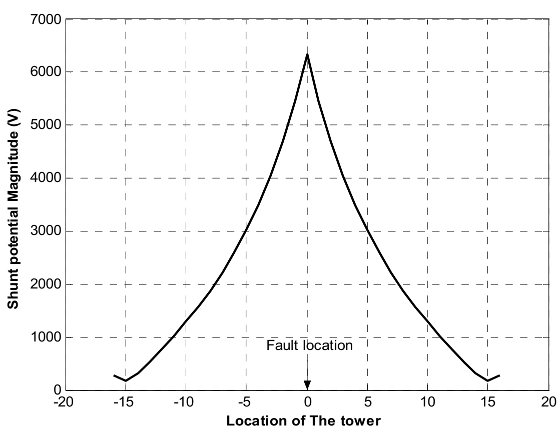

Figure 6: Tower Potential Magnitude With Position

B.3 Pipeline Potential Magnitude (Inductive)

As shown in figure (7) the maximum pipeline inductive interference appeared at the fault location (i.e. at the center of the pipeline) and decreased at both sides. The magnitude of the inductive interference is decreased by increasing the separation distance between the two systems.

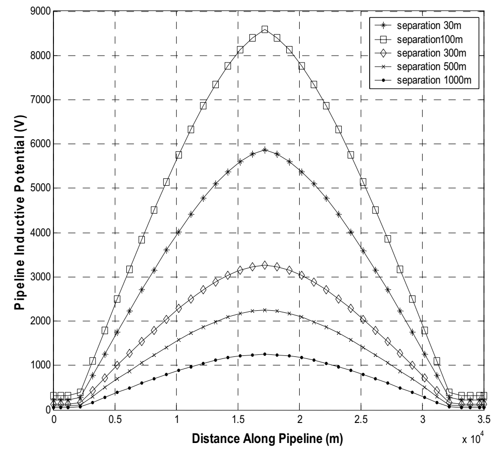

Figure 7: Pipeline Inductive Potential
Along The Parallel Distance

B.4 Pipeline Potential Magnitude (Conductive)

The conductive component at different separation distance is given in figure (8).From this figure and in comparison with figure (7) it is clear that the inductive component is greater in magnitude and extent than the conductive component

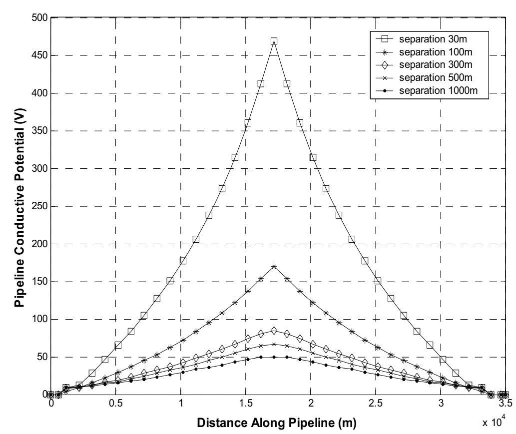

Figure 8: Pipeline Conductive Potential
along the Parallel Distance

B.5 Pipeline coating stress voltage

It appears with maximum value at fault location on the pipeline as shown in figure (9). The total coating stress voltage can be obtained by adding up the inductive and conductive components, taking into account the phase angle between them.

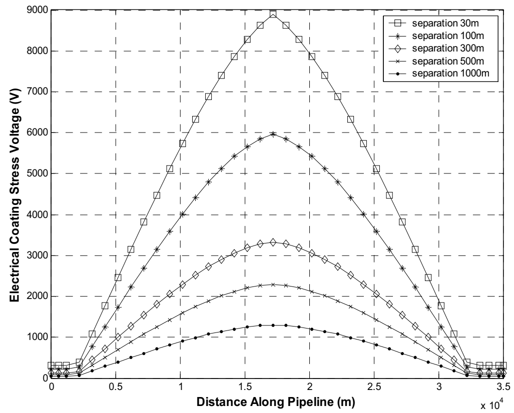

Figure 9: Pipeline Coating Stress Voltage Along The Pipeline

B.6 Pipeline Longitudinal Current

In this case (fault condition) the longitudinal appears at its maximum values on both side ends of the parallel pipeline and decreases at middle of the pipeline .From the results the maximum values of the longitudinal currents when the separation distance between the two systems is minimum and decreases when the separation distance increased. Figure (10) gives the values of current at different separation distances between the two systems along the length of the parallel portion

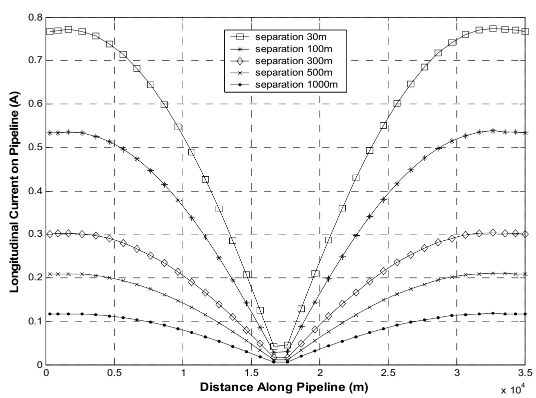

Figure 10: Longitudinal Current (A) on Pipeline

IX CONCLUSIONS

• As consequence of the AC power lines and buried pipeline sharing right-of-way an AC voltage can be induced on the pipeline by inductive and conductive interference during steady state conditions and faulty conditions.

• The magnitude of the induced voltage and current on the pipeline is a function of a number of variables describing the configuration, location and soil resistivity of pipelines.

• It is obviously demonstrated that the pipeline potential will be reduced by increasing the separation distance between T.L and pipeline.

• The developed software program used for simulation showed to be an effective mean of calculating the voltage induced on pipeline. •Longitudinal current and the allowable electrical stress on coating is high at the mid point of pipe in normal condition but in case of fault condition the longitudinal current is minimum at fault location .

• The electrical coating stress voltage is equal to the sum of inductive component and conductive component but take into account the phase angle between them.

• By the developed mitigation method it is possible to design new systems without interference.

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