ON THE MECHANISMS OF ELECTROMAGNETIC INTERFERENCE BETWEEN ELECTRICAL POWER SYSTEMS AND NEIGHBORING PIPELINES

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Abstract: *The mechanisms of electromagnetic interference between a power line and a neighboring pipeline using electromagnetic field theory are discussed based on a simple right-of-way scenario. First, the field theory approach is used to model the complete conductor network under consideration, as is. The inductive, capacitive and conductive interference effects between all the elements in the network are simultaneously taken into account in one single step. The computed results are then used to develop new computer models whereby the effects of the inductive, capacitive and conductive interference effects can be separated. This allows us to compare the field-theory-based results with the results obtained from other approximated approaches, such as grounding analysis (conductive effects) and circuit-based models (inductive effects). The effects of a typical mitigation system on the interference levels are also studied. The results presented in this paper clearly illustrate the mechanisms of electromagnetic interference between electrical networks and neighboring metallic utilities.*

1. INTRODUCTION

Electromagnetic interference caused by electric transmission and distribution lines on neighboring metallic utilities such as gas and oil pipelines became a major concern in the early 60's due to the significant increase in the load and short-circuit current levels needed to satisfy the energy required by the phenomenal industrial growth of Western nations. Another reason for increased interference levels originates from the more recent environmental concerns which impose on various utilities the obligation to share common corridors in an effort to minimize the impact on wildlife and other related threats to nature.

Although electromagnetic interference problems were analyzed in the early days of telegraph and telephone mainly as an inductive coupling problem between telecommunications circuits (crosstalk) and between electric lines and telecommunications lines (electric noise), it is only in the mid 60's that the first detailed investigations of a realistic interference analysis including power lines and pipelines were published by Pohl [1] and Favez et al [2]. These early analysis tools were however limited in several ways, which have been overcome by more recent research work [3-7]. While earlier software was based on the assumption of essentially parallel facilities, cases arise in practice in which both the electric power lines and the pipelines follow curved paths which intersect one another, diverge, reconverge, etc., making them difficult to model accurately. Recently, field-theory based software does away with the parallel assumption and accounts simultaneously for magnetic (inductive), resistive (conductive) and capacitive (electrostatic) coupling between all elements (both buried and aboveground) modeled [8,9]. The new generation of software can also model high-frequency transients in the time domain. As a result, the response of a pipeline to a lightning strike or other types of transients on a nearby transmission line can be computed.

Practically, study of interference effects from AC power lines in pipelines, railways, communications lines and other such structures has resulted in numerous research reports, standards and papers [12-18] in recent years. As these references show, determination of interference effects in a typical right-of-way is a complex procedure requiring not only a good knowledge of conductor layout, power line and pipeline electrical characteristics and electrical system parameters, but also an accurate representation of the soil structure.

Previous work by Dawalibi et al [11] was essentially using an analytic approximation to do the SOMMERFELD integrals in the field theory. This paper shows more accurate results to the previous work by a numerical double-integration instead of an analytic approximation to the SOMMERFELD integrals. Furthermore, the inductive effects are compared to those obtained using the circuit approach. Finally, the performance of a typical mitigation system with respect to mitigation of both inductive and conductive interference is illustrated.

2. DESCRIPTION OF THE PROBLEM

Figure 1 presents the model of the complete electromagnetic interference network under consideration. The network consists of one transmission line phase conductor, one shield wire and one pipeline. The modeled portion of the transmission line is about 10 km (9620 m) long. For simplicity, only one phase conductor and the shield wire have been modeled. The phase conductor is 27 m above grade. Its diameter is 38.2 mm. The relative resistivity (with respect to annealed copper) of the phase conductor is 4 and its permeability (relative to air) is 10. The shield wire is parallel to the phase conductor and is 35 m above grade. Its diameter is 12.7 mm. The relative resistivity of the shield wire is 1.67 and the relative permeability is 1. The transmission line span length is 400 m. Each span is delineated by a pole structure represented simply as a single vertical wire connecting the shield wire to a 10 m long ground rod approximating the grounding afforded by the pole foundation.

The pipeline is centered in the corridor and is 40 m away from the transmission line center. The pipeline length of exposure is 4400 m. At each end of the exposure the pipeline veers away perpendicularly and continues for 1000 m before terminating. The outer diameter of the pipe is 40 cm and its wall thickness is 10 mm. The pipeline is buried 2 m below grade. The relative resistivity of the pipe is 12 and its permeability is 250. The pipeline's effective coating resistivity is 3,048,781 ohm-m (as computed based on a leakage resistance of 12131.7 ohm-m^2 and a thickness of 5 mm). A fault current of 25,000 A is assumed to be flowing from each end of the transmission line during a fault at the central pole of the right-of-way.

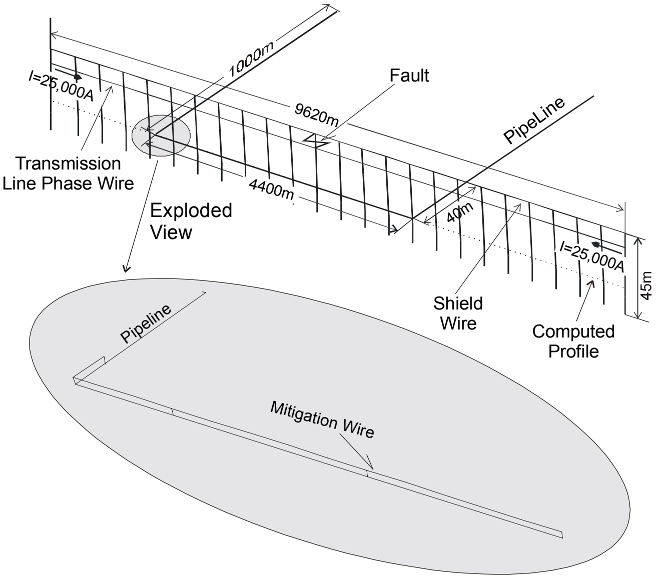

Figure 1. The complete model of the network.

A highly effective means of mitigating excessive pipeline voltages is the installation of gradient control wires. In this paper, a typical mitigation system is applied to the exposure pipeline. A bare 14 mm diameter conductor is buried parallel to and 1 m from the pipeline at the depth of 1.5 m below grade. The wire is regularly bonded to the pipeline (every 200 m for the first 400 m at each end and every 400 m for the rest of the middle portion of the pipeline).

3. METHODOLOGY OF THE STUDY

The field approach used here is based on electromagnetic theory. In order to get higher accuracy results, a numerical evaluation (Gaussian integration method) of SOMMERFELD integrals is used instead of an analytic approximation. Firstly, the model of the complete conductor network (as shown in Figure 1) is built. Secondly, the inductive, conductive and capacitive interference (it can be ignored in this case because the pipeline is buried) effects between all the elements in the network are simultaneously computed in one single step. Then, the currents going through each pole extracted from the results are used to develop two other networks to model separately the effects of the inductive and conductive interference. This procedure was applied to both the "No Mitigation" and "With Mitigation" cases.

For the purpose of computing touch voltages in the vicinity of the pipeline, a long profile consisting of 1960 observation points lying on the surface of the soil and right above the pipeline was specified starting at one end of the transmission line corridor and ending at the other end (total profile length is 9620 meters). First, the earth surface potential and pipeline potential rise at various locations were calculated. The touch voltages were determined from the vectorial difference between the pipeline potential rise and soil potential in the vicinity (within a radius of 3 m from the pipeline centerline).

The study was performed using the HIFREQ and SPLITS modules of the CDEGS software package [10].

4. THE MECHANISMS OF INTERFERENCE

AC interference in a pipeline sharing a corridor with a power line consists of an inductive component and a conductive component. During normal load conditions on the power line, only the inductive component is present and is induced in the pipeline by the magnetic field generated by the power line. This level of interference increases with decreasing separation and angle between the conductors, with increasing soil resistivity, as well as with increasing current magnitude and frequency in the energized conductor.

When a single-phase-to-ground fault occurs on a transmission line, the faulted structure discharges a large current into the earth and hence raises the soil potential in its vicinity. If the pipeline coating has a high resistivity, the pipeline will remain at a relatively low potential. The difference in potential between the pipeline and the surrounding earth represents the conductive interference. The magnitude of the conductive interference is primarily a function of GPR of transmission line structure, separation distance, size of structure grounding system and soil structure.

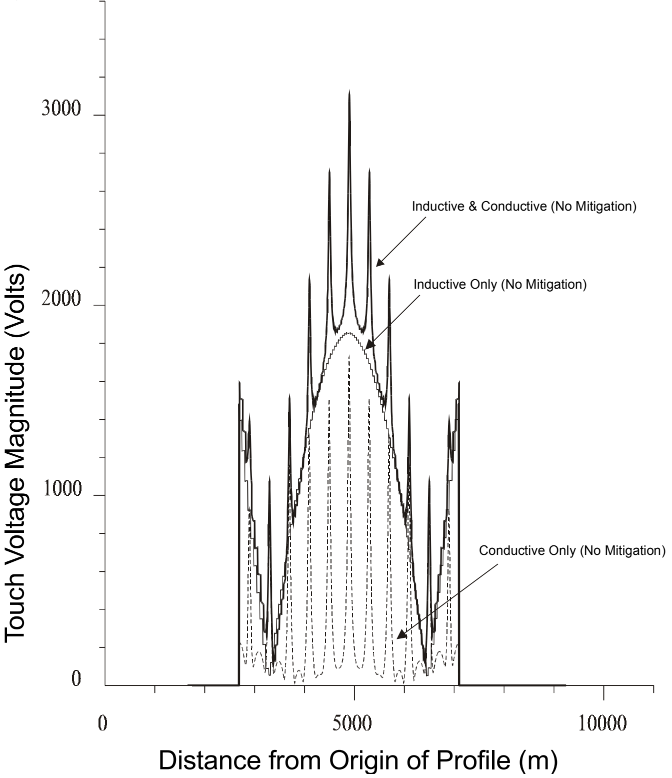

Figure 2. Touch voltages along pipeline, without mitigation.

Figure 2 and 3 show the touch voltage magnitude along the pipeline with and without mitigation case, respectively. From these figures, we can easily see the different contributions of the inductive and conductive components. Also, we can conclude:

1. The touch voltage is a defined quantity only where the pipeline is present along the profile: elsewhere, it has been set to zero.
2. For the conductive interference, the curve reaches a peak at each tower location, where the current flows into the earth.
3. The inductive interference decreases with increasing distance from the center of the pipe but peaks at the pipe bending point because of the longitudinal current discontinuity.
4. The inductive component is greater in magnitude and extent than the conductive component.
5. The inductive and conductive components are additive near the fault location, although the magnitude of their vector sum falls somewhat short of the sum of their individual magnitudes.

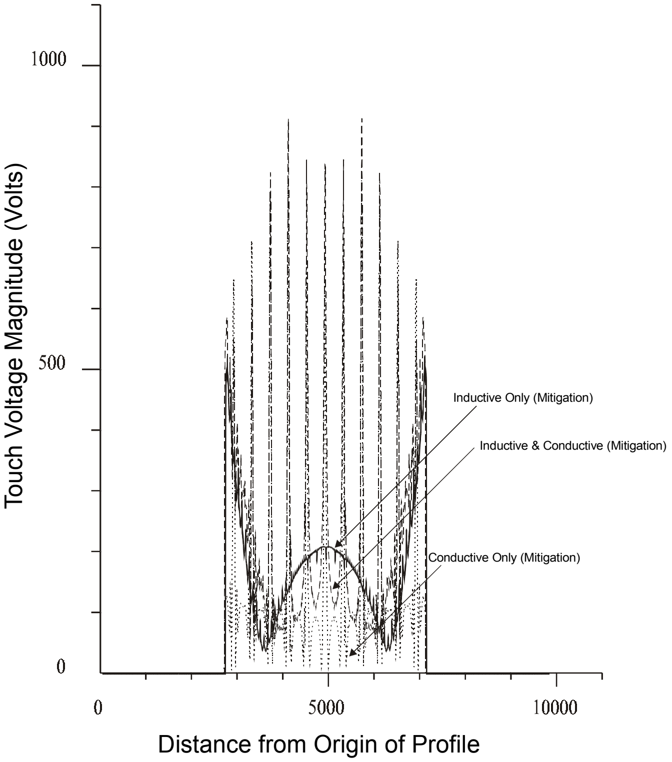

Figure 3. Touch voltages along pipeline, with mitigation.

5. COMPARISON FIELD_THEORY_BASED RESULTS WITH RESULTS FROM THE CRICUIT MODEL FOR INDUCTIVE INTERFERENCE

The circuit approach computes the line parameters of the entire network using appropriate line constant formula or specialized software, then a circuit model representing the network is then built. This circuit model is then solved to yield the inductive interference component. The figure 4 and 5 compare the induced touch voltage magnitude of the pipeline by the magnetic field generated by the transmission line from the field theory to the results obtained from the circuit model for both no mitigation and mitigation cases, respectively. The difference between them is about 6.86% for no mitigation case, and 15% for mitigation case maximum.

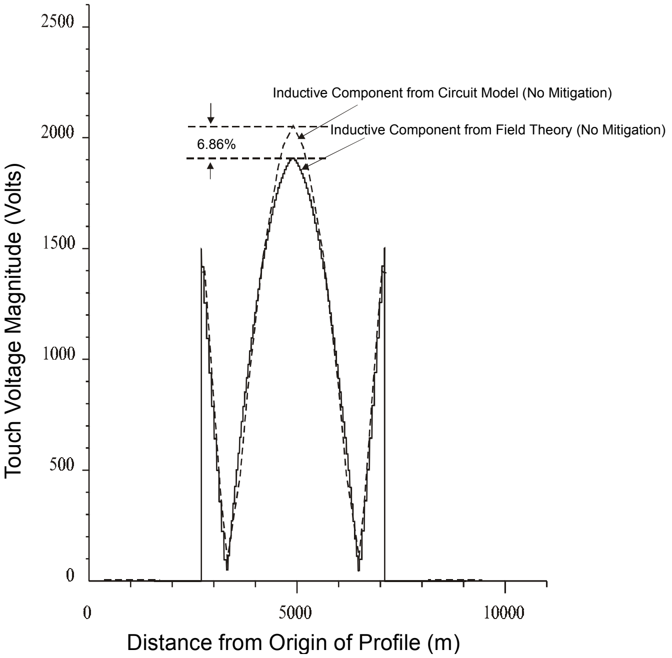

Figure 4. Touch voltages along pipeline for inductive component without mitigation.

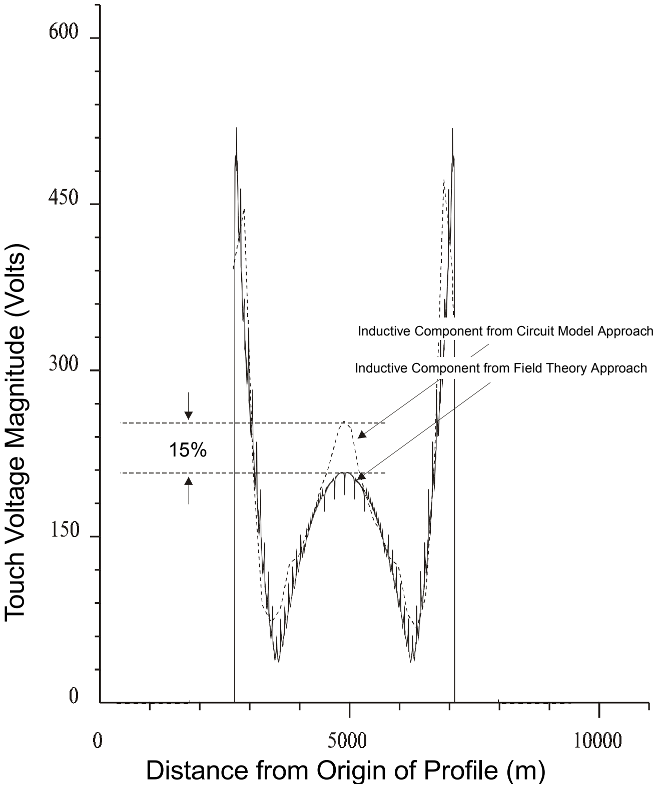

Figure 5. Touch voltages along pipeline for inductive component with mitigation.

6. MITIGATION EFFECTS

Mitigation systems are designed to reduce touch voltages and coating stress voltages to acceptable levels during power line load and fault conditions. A very highly effect means of mitigation excessive pipeline potentials is the installation of gradient control wires. With respect to inductive interference, the gradient control wires not only provide good grounding for the pipeline and thus lower the absolute value of the pipeline potentials (i.e., the potential with respect to remote earth), they also raise earth potentials in the vicinity of the pipeline such that the difference in potential between the pipeline and the local earth is reduced. As a result, touch voltages and coating stress voltages are significantly reduced. Similarly, for the conductive interference, these wires reduce the potential difference between the earth surrounding the pipeline and the pipeline steel by allowing current to flow between them. As a result, earth potentials arising from nearby faulted structures decrease and potentials transferred to the pipeline by the faulted structures increase.

Figures 6, 7 and 8 compare the touch voltage magnitude of the pipeline with mitigation and without mitigation for the combined inductive and conductive components, the inductive only and the conductive only cases, respectively. From these figures, we can conclude that the mitigation significantly reduces touch voltages in all of these cases, i.e., conduction, induction and both. The total worst touch voltage is decreased by 88.6% when gradient control wires are installed. At the center of the pipeline (the fault location), the touch voltage is decreased by 73.5% for the inductive component and 62.4% for the conductive component.

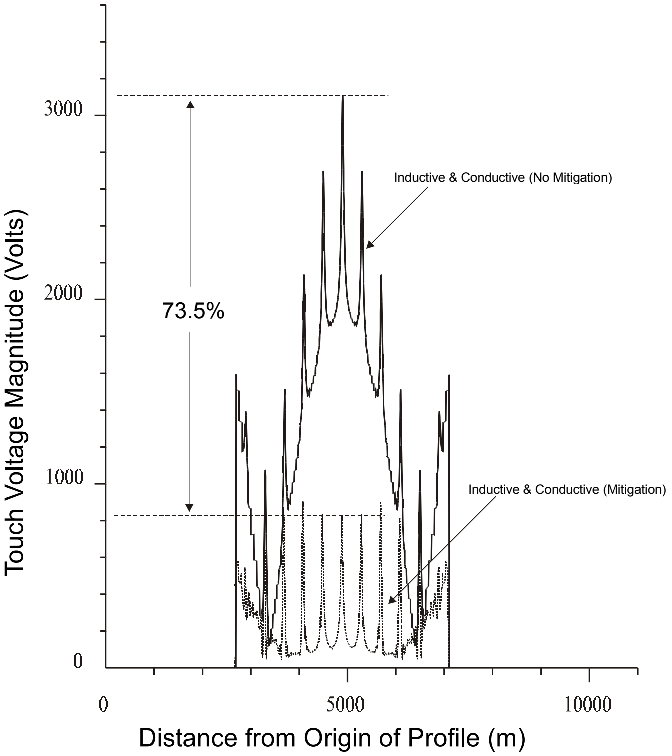

Figure 6. Touch voltages along the pipeline for the inductive & conductive components combined.

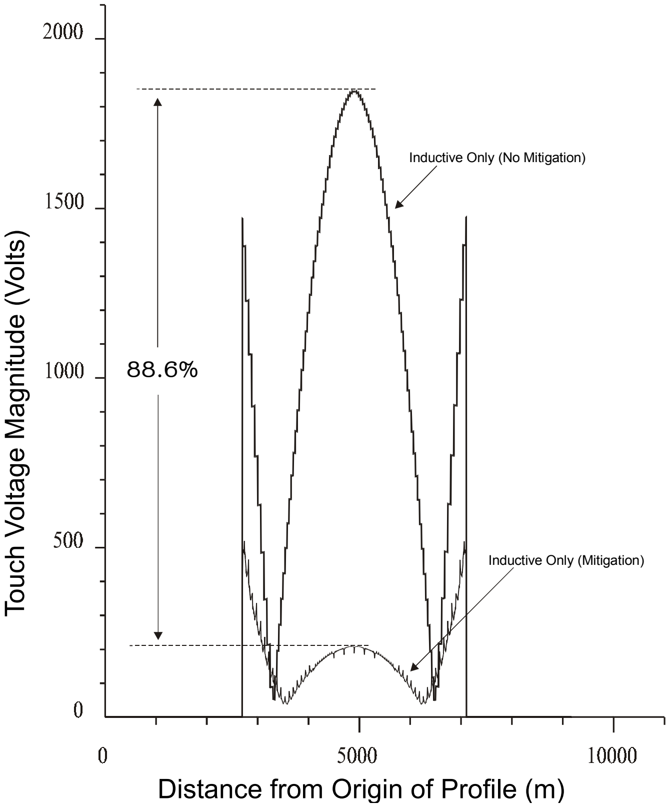

Figure 7. Touch voltages along pipeline: induction alone.

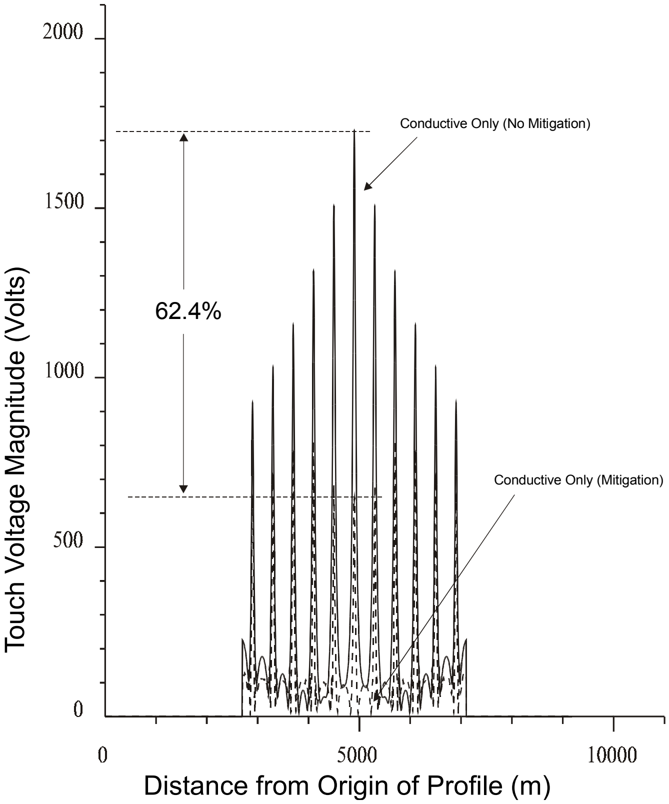

Figure 8. Touch voltages along the pipeline: conductive alone.

7. CONCLUSIONS

The electromagnetic interference between a power line and a buried neighboring pipeline consists of inductive and conductive coupling. The field approach accounts simultaneously for all the coupling mechanisms in one single step. This paper has examined the mechanisms of AC interference with a high accuracy integration method.

The inductive interference computed from the field theory has been compared with the results obtained from the circuit mode approach, the maximum difference is less than 15% for the studied case.

The installation of mitigation wires (also known as gradient control wires) can significantly reduce pipe touch voltages by bringing earth and pipeline steel potentials closer to one another; in the process, the absolute values of these earth and steel potentials are both reduced, since they tend to be out of phase before the mitigation is introduced and thus cancel one another.

Future work will examine non-parallel utilities and more complicated electrical networks such as substation grid included. Also, a more detailed comparison field-theory-based results with results from the circuit model approach will be carried out.

8. ACKNOWLEDGEMENTS

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10. BIOGRAPHIES

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- Simplified Rules for Grounding Customer-Owned High Voltage Substations, a Canadian Electrical Association project undertaken to revise portions of Section 36 (Part I) of the Canadian Electrical Code.
- Safety Grounding Practices for Personnel Working on Distribution Systems up to 50 kV, (Phase II interim report), a Canadian Electrical Association project exploring temporary safety grounding methods by means of a vast parametric analysis involving thousands of computer simulations.

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