ELECTROMAGNETIC INTERFERENCE CAUSED BY A POWER SYSTEM NETWORK ON A NEIGHBORING PIPELINE

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ABSTRACT

This paper examines the mechanisms of electromagnetic interference caused by a power system substation, including a portion of its incoming and outgoing transmission lines on a neighboring pipeline. Two approaches, a circuit approach and a field approach, are used to carry out the study. The circuit model approach requires that the line parameters of the entire network be computed first, using appropriate line constant formulae or specialized software. Lumped elements, such as ground impedances of substation grounding grids and transmission tower grounds, are computed using appropriate tools such as grounding software. A circuit model representing the network is then built. This circuit model is then solved to yield the inductive interference component. The conductive interference component is usually determined using appropriate grounding software. The field approach is based on electromagnetic field theory. 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 can be used to develop a network model whereby the effects of the inductive, capacitive and conductive interference effects can be separated, allowing one to compare the field-theory-based results with the results from the circuit model approach. The results presented in this paper clearly illustrate the mechanisms of electromagnetic (EM) interference between electrical networks and neighboring metallic utilities such as pipelines, and the effects of a substation grid on the EM interference.

INTRODUCTION

The mechanisms of electromagnetic interference between a power system network and a neighboring pipeline at low frequencies have been traditionally divided into three categories: inductive, conductive and capacitive coupling. Conventionally, the inductive interference is analyzed with a circuit model approach and the conductive interference is determined using appropriate grounding software. The inductive and conductive components are then added together. In the circuit model approach, the computation of the line parameters is based on two essential assumptions: (1) Conductors are infinite in length; and (2) conductors are parallel. Cases arise in practice in which long electric power lines and pipelines, sharing the same corridor, follow curved paths which intersect one another, diverge, reconverge, etc., making them difficult to model accurately with a circuit model approach. Recently, field-theory-based software does away with the assumptions and accounts simultaneously for inductive, conductive and capacitive coupling between all the buried and aboveground elements modeled [1-23].

Previous work by Dawalibi *et al* clearly illustrate the mechanisms of electromagnetic interference between electric networks and neighboring metallic utilities [11] and compares the results from the circuit model approach with the results from the field-theory-based approach for a simple right-of-way scenario [23]. This paper shows the results caused by a more complex right-of-way configuration, which consists of a power system substation, including a portion of its incoming and outgoing transmission lines and a neighboring pipeline. Furthermore, the effects of a typical substation grounding grid on the inductive and conductive interference are discussed. Finally, detailed comparisons between the results from the field approach and the circuit approach are presented for this right-of-way model.

DESCRIPTION OF THE PROBLEM

Figure 1 presents the complete model of the right-of-way network under consideration. The network consists of a power substation, including a portion of its incoming and outgoing transmission lines (T/L) and a neighboring pipeline. The modeled portion of the T/L 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. The shield wire, an optical fiber conductor, is parallel to the phase conductor and is 35 m above grade. Its diameter is 12.7 mm; its relative resistivity (with respect to copper) is 1.67 and relative permeability (with respect to free space) is 1. The shield wire is connected to ground at each end through an appropriate impedance of 10 ohm, to simulate a long T/L line. The T/L 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 substation grounding system is a 200 m by 100 m grounding grid. The ground conductors are copper with a radius of 0.0067 m. The grid is buried at

a depth of 0.5 m and is connected to the central pole of the right-of-way.
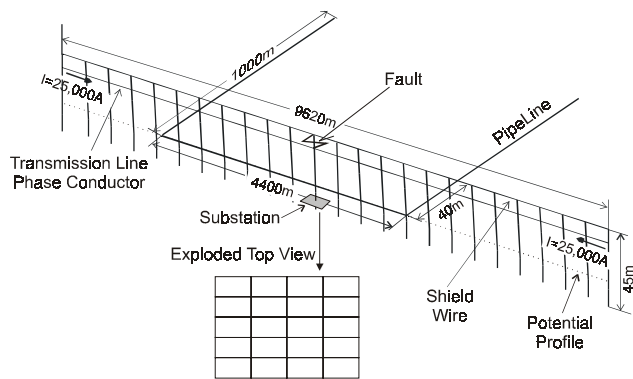

Figure 1. Complete Model of the Network.

The pipeline is centered length-wise in the corridor and is 40 m away from the T/L center. The pipeline length of exposure is 4400 m and this portion is parallel to the T/L. 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 wall is 12 and its relative 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 substation.

METHODOLOGY OF THE STUDY

The field approach used here is based on electromagnetic field theory. First, the model of the complete conductor network (as shown in Figure 1) is built. Second, the inductive, conductive and capacitive interference effects (the latter can be ignored in this case because the pipeline is buried) between all the elements in the network are simultaneously computed in one single step. In order to compare the inductive and conductive components alone with those computed using the circuit model approach, the computed results are used to develop two other models to simulate separately the effects of the inductive and conductive interference.

The circuit model approach requires that the line parameters of the entire network be computed first, using line constants software. Lumped elements of ground impedances of the substation grid and transmission tower grounds are computed using appropriate grounding software. A circuit model representing the network is then built. Finally, this circuit model is solved to yield the inductive interference component.

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, right above the pipeline, was specified, starting at one end of the transmission line corridor and ending at the other (total profile length is 9620 meters). Earth surface potentials were calculated at the points along the profile. The touch voltages were computed by subtracting vectorially the potential rise of the nearest pipe segment (if one is found within a distance of 3 m) from the earth potentials.

The study was performed using a software package [10], which supports both the field-based and circuit-based approaches.

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 impressed on 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 conductors. Induced voltage peaks typically occur at phase transpositions and abrupt changes in separation distance between the pipeline and transmission line.

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 potential will remain relatively unaffected by the high potential of the surrounding soil. This difference in potentials between the pipeline and the surrounding earth due to currents discharged into the earth by a faulted transmission line structure represents the conductive interference. The magnitude of the conductive interference is primarily a function of ground potential rise (GPR) of the transmission line structure, separation distance, size of the structure grounding system and soil structure characteristics. During a fault, inductive interference is present as well, with a peak occurring at the fault location.

Figures 2 shows the touch voltage magnitude along the pipeline for the right-of-way network described above during a fault at the substation. From the figure, one can easily see the individual contributions of the inductive and conductive components.
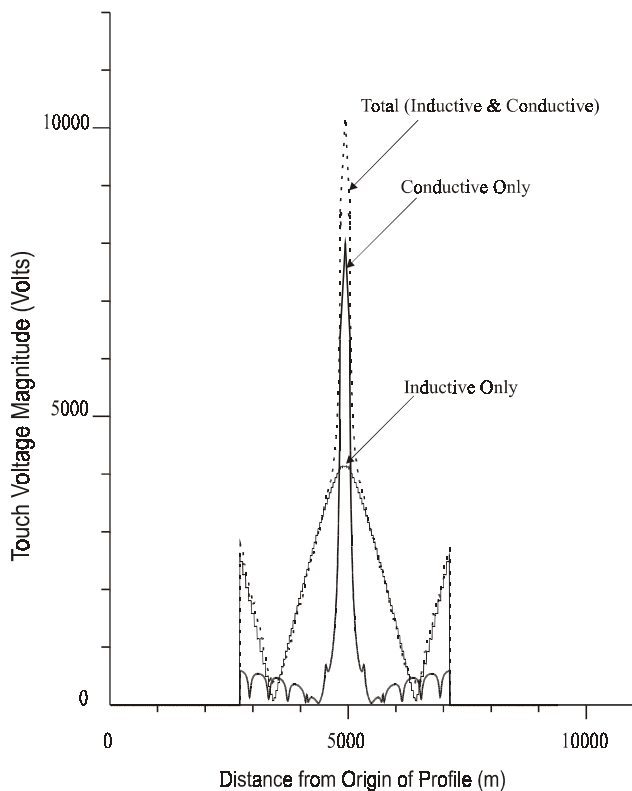
Figure 2. Touch Voltages Along Pipeline (Substation Grid Present).

EFFECTS OF A SUBSTATION ON THE INTERFERENCE LEVELS

Appropriate power system grounding is important for maintaining reliable operation of electric power systems, protecting equipment, and insuring the safety of public and personnel. The grounding grid can change the fault current and voltage distributions dramatically. Figure 3 shows the touch voltage along the pipeline for the same right-of-way network as in Figure 1, but without the substation grid. From Figures 2 and 3, we can see that:

1. The conductive component curves are quite different in magnitude. The maximum conductive interference is increased from 1720 V to 8200 V when the substation grounding grid is present. This is because the substation grid covers a much large area than a tower. As a result, the grid has a much lower ground impedance than the tower grounding and more fault current is discharged into the earth through the substation grounding grid, producing a greater transfer of potential to pipeline location. However, the pipeline potential will remain about the same because the pipe is well coated and not connected to the substation. Therefore, the pipeline touch voltages from the conductive interference alone are higher when the substation is present.

2. The inductive interference level is also higher when the substation is present. The level of pipeline inductive interference is due to the longitudinal currents in both the phase conductor and the shield wire. The inductive interference in the pipeline due to the shield wire current reduces that due to the phase conductor current because the current directions are opposite. Since less current will flow in the shield wire due to the presence of the substation, which effectively drains fault current to earth, the interference reduction effect will be smaller. Therefore, the resultant inductive interference level in the pipeline will be higher.
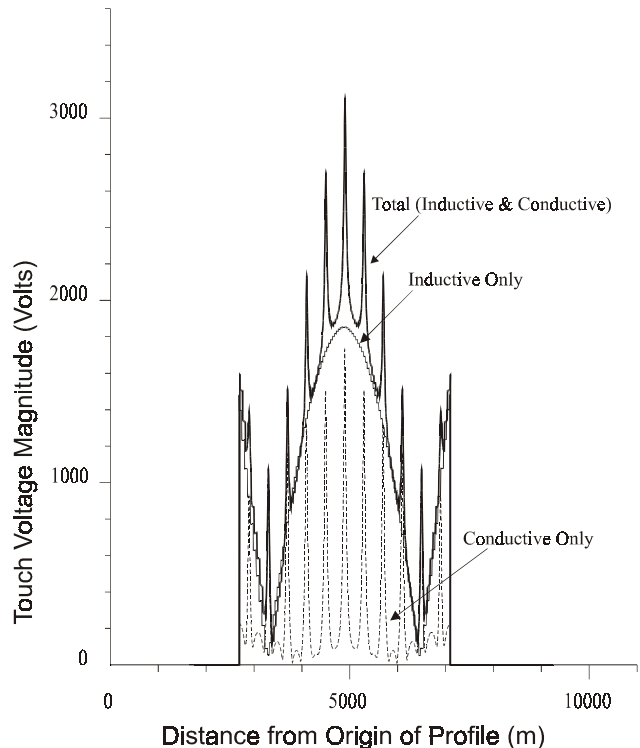

Figure 3. Touch Voltages Along Pipeline (No Substation Grid).

COMPARISON OF THE FIELD APPROACH AND CIRCUIT APPROACH RESULTS

The circuit approach requires the computation of the line parameters of the entire network and the setup of a circuit model representing the network. This circuit model is then solved to yield the inductive interference component. In the computation of the line parameters, the lines are assumed to be parallel and infinite in length. Obviously, these assumptions may lead to inaccuracy in the computation of the inductive interference. To evaluate this inaccuracy for the power system presented in this paper, the electromagnetic field theory approach is used to make the comparison. The conductive interference computed based on standard grounding software is also compared with the field approach result.
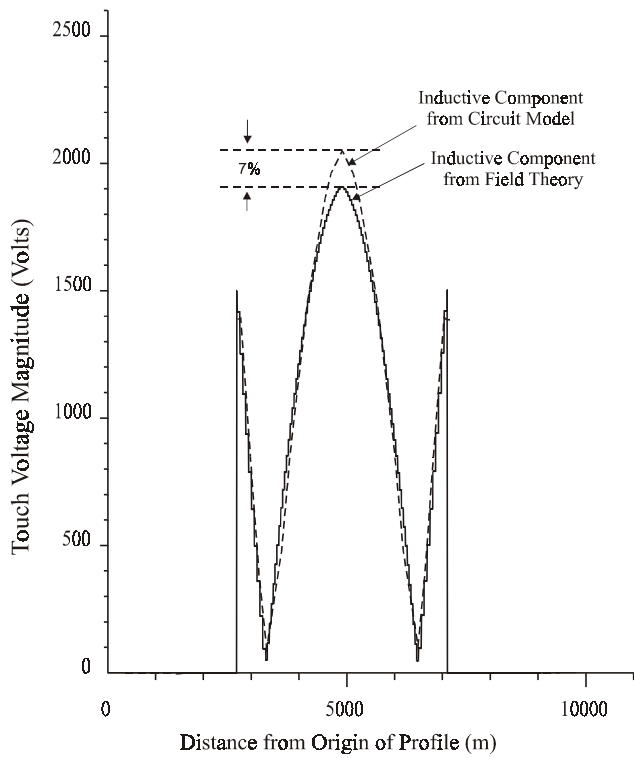
Figure 4. Touch Voltages Along Pipeline Due to Inductive Component (No Substation Grid).
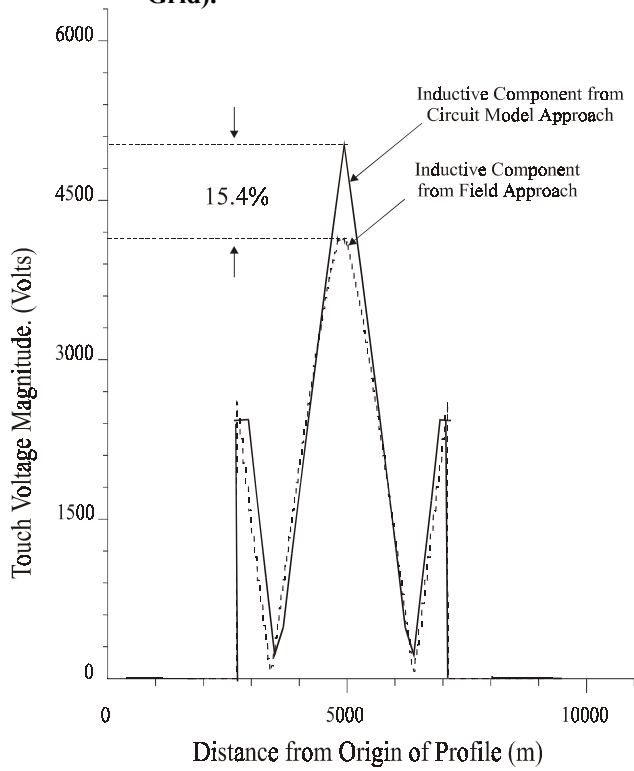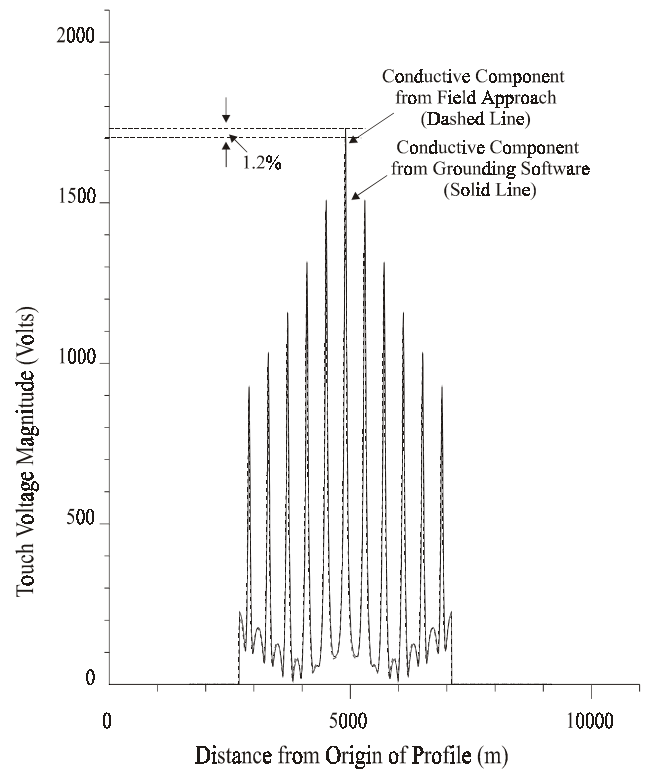

Figure 6. Touch Voltages Along Pipeline Due to Conductive Component (No Substation Grid).

Figure 5. Touch Voltages Along Pipeline Due to Inductive Component (Substation Grid Present).
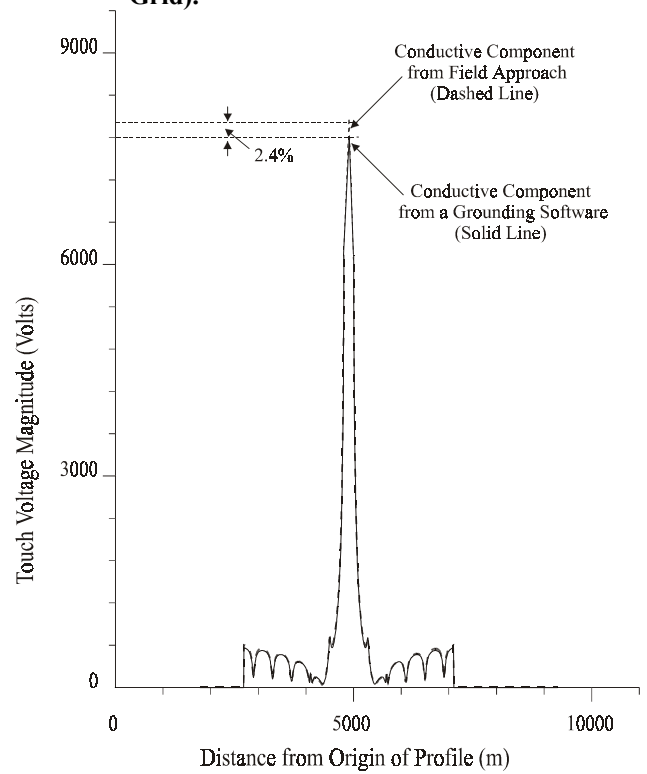

Figure 7. Touch Voltages Along Pipeline Due to Conductive Component (Substation Grid Present).

Figures 4 and 5 compare the induced touch voltage magnitudes along the pipeline computed using the field theory approach with those obtained from the circuit model for both cases. The difference between them is less than 7% for the case without the substation and 15% for the case with the substation. Figures 6 and 7 compare the conductive interference using the field approach with that using a standard grounding software for both cases. The differences are small: 1.2% for the case without the substation grid and 2.4% for the one with the substation grid.

CONCLUSIONS

Electromagnetic interference caused by a power system substation on a buried neighboring pipeline has been analyzed using electromagnetic field theory. The field approach accounts simultaneously for all the coupling mechanisms in one single step. This paper has examined the mechanisms of AC interference by separating the effects of each individual component i.e., inductive, conductive and capacitive (although negligible).

A substation grid can change the distribution and magnitude of both conducted and induced currents. An accurate grounding analysis should be made carefully to account for these effects.

The inductive interference and the conductive interference computed using the field theory have been compared to the results obtained from the circuit approach and grounding software, respectively. The maximum difference between the two approaches is less than 15% for the cases studied which involve a parallel pipeline exposure.

Future work will study the effects of the length and angle of conductor exposure on the computation accuracy of the inductive interference using a circuit approach in order to develop more accurate simplified methods based on circuit theory.

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BIOGRAPHIES

Ms. Yexu Li received the B.Sc. degree in Geophysics from Beijing University and the M.Sc. degree in Seismology from the Chinese Academy of Sciences in 1986 and 1989, respectively. She received the M.Sc. degree in Applied Geophysics from Ecole Polytechnique of the University of Montreal in 1996 and the Graduate Diploma in Computer Sciences from Concordia University in 1998.

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Ms. Li has co-authored several papers on geophysics and electromagnetic interference analysis.

Dr. Farid P. Dawalibi (M'72, SM'82) was born in Lebanon in November 1947. He received a Bachelor of Engineering degree from St. Joseph's University, affiliated with the University of Lyon, and the M.Sc. and Ph.D. degrees from Ecole Polytechnique of the University of Montreal. From 1971 to 1976, he worked as a consulting engineer with the Shawinigan Engineering Company, in Montreal. He worked on numerous projects involving power system analysis and design, railway electrification studies and specialized computer software code development. In 1976, he joined Montel-Sprecher & Schuh, a manufacturer of high voltage equipment in Montreal, as Manager of Technical Services and was involved in power system design, equipment selection and testing for systems ranging from a few to several hundred kV.

In 1979, he founded Safe Engineering Services & technologies, a company specializing in soil effects on power networks. Since then he has been responsible for the engineering activities of the company including the development of computer software related to power system applications.

He is the author of more than one hundred papers on power system grounding, lightning, inductive interference and electromagnetic field analysis. He has written several research reports for CEA and EPRI.

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Since September 1990, he has been with the R & D Dept. of Safe Engineering Services & Technologies in Montreal, where he is presently serving as manager of the Analytical R & D Department. His research interests are in transient electromagnetic scattering, EMI and EMC, and analysis of grounding systems in various soil structures.

Dr. Ma is the author of more than sixty papers on transient electromagnetic scattering, analysis and design of reflector antennas, power system grounding, lightning, and electromagnetic interference. He is a member of the IEEE Power Engineering Society, the IEEE Standards Association, and a corresponding member of the IEEE Substations Committee and is active on Working Groups D7 and D9.