INTEGRATED METHOD IN ELECTROMAGNETIC INTERFERENCE STUDIES

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ABSTRACT:

This paper studies the electromagnetic interference problems arising in corridors shared by transmission lines, pipelines, and railways, etc. A new circuit model method for analyzing interference problems is introduced. This method can be used to compute the combined inductive, capacitive, and conductive interference level efficiently and accurately. Practical examples are examined and results obtained using the new method are presented and compared with those obtained using the conventional circuit model method and the exact electromagnetic field method. It is shown that the new circuit model can be applied to problems which cannot be solved using the conventional circuit model.

KEY WORDS:

Safety, Electromagnetic Interference, Coating Stress Voltage, Induced Potential

1. Introduction

Presently, there are generally two ways of analyzing electromagnetic interference between transmission lines, railways, pipelines, communication lines or other metallic circuits (victim circuits) which are parallel to the transmission lines: (1) electromagnetic field method (EFM); (2) conventional circuit method (CCM) along with grounding analysis. In the EFM case, the total interference level can be obtained in one step without the need to compute each individual component such as inductive and conductive components separately. The main limitation of the EFM is that it is difficult to handle very long right-of-ways with many circuits. In the CCM case, interference levels due to induction and conduction are computed separately. The total interference level is then obtained by combining the inductive and conductive components, which is always a time consuming process. When the victim circuit is connected to the electrical substation grounding grid which is usually connected to the overhead ground wires, the total interference level can no longer be computed accurately by using the CCM approach.

The objective of this paper is to show that by improving the CCM, the total interference level can be computed efficiently and accurately. The new method has two distinctive advantages: (1) significantly improved the efficiency of the interference analysis as compared to the CCM by eliminating the time consuming process of combining the inductive and conductive components; (2) able to provide accurate solution to the problem of pipelines connected to electric substation grounding systems, which cannot be solved by using the CCM.

Examples of interference problems are analyzed using the new circuit method. The results are compared with those obtained using the CCM and the EFM approaches.

2. Description of the Analysis Methods

When a pipeline or railway is parallel to a nearby transmission line, currents and potentials are induced in the pipeline or railway under steady state conditions and fault conditions. High induced potentials may be a safety hazard for personnel and may also cause damages to pipeline, railway, and pipeline coating. One of the important requirements for such an interference study is to accurately evaluate the pipeline coating stress voltage under fault conditions. The pipeline coating stress voltage consists of two parts: the inductive component and the conductive component. The inductive component is the pipeline potential with respect to the earth surrounding the coating when the transmission towers are not energized. The inductive component is caused by the magnetic induction due to the current flowing in the nearby parallel transmission line. The conductive component is the potential of the earth surrounding the coating with respect to the unenergized pipeline. The conductive component is caused by the nearby transmission line towers and substation grounding system that discharge fault currents to the earth.

In a CCM analysis, line parameters are computed first for the common corridor of the transmission line, pipeline, and railway based on their geometric dimensions and conductor characteristics. A circuit model is then built to compute the induced potential on the pipeline and railway. As mentioned above, the induced potential is the inductive component of the pipeline coating stress voltage. To compute the conductive component, a grounding analysis must be carried out in which the transmission line towers are modeled as energized structures and the coated pipeline is modeled as an unenergized structure. The total pipeline coating stress voltage is the sum of the inductive and conductive components. This method gives accurate results when the pipeline coating resistance is high and when the pipeline is not connected to grounding systems which in turn are connected to overhead ground wires of the transmission line. When the pipeline coating resistance is not very high or the pipeline is installed with gradient control wires, the accuracy of the results will decrease. When the pipeline is connected to grounding systems which are connected to overhead ground wires of the transmission lines, this method is no longer applicable because the inductive component and the conductive component can no longer be easily separated. In this case, the EFM can be used to obtain accurate results. Examples of the CCM can be found in [1-2].

In a EFM analysis, a conductor network is modeled which includes the pipeline, the transmission line phase conductors, the overhead ground wires together with the towers and grounding systems to which the overhead ground wires are usually connected. The EFM can produce the total interference effect in a single step, avoiding the separation of the inductive and conductive components which is necessary in the CCM. The limitation of the EFM is that when the common corridor is very long and consists of many circuits, the modeling and computation time can be long. Examples of the EFM can be found in [3-4].

The new circuit method presented in this paper is based on the CCM. By introducing an EMF (electromotive force) term in the grounding analysis computation, the total interference level can be obtained accurately and efficiently even for cases when the pipeline coating resistance is low and/or the pipeline is connected to grounding systems which are connected to overhead ground wires. Similar to the CCM, the first step is to build a circuit model and compute the induced potential on the pipeline and the currents discharged by the transmission line towers. The new method also computes the induced EMF in the pipeline in the first step. The second step in the CCM is the computation of the conductive component by modeling the conductor network and carrying out a grounding analysis. The transmission line towers are energized with the tower currents computed in the first step while the pipeline remains unenergized. In the new method, the second step will produce the total pipeline stress voltage by modeling the conductor network with the towers energized by currents and with the pipeline energized by EMF values computed in the first step. Obviously, the new method eliminates the tedious process of combining the inductive and conductive components. More importantly, this method, unlike the CCM, can also be used to compute the total coating stress voltages when pipelines are connected to overhead ground wires or grounding systems.

3. Practical Examples

3.1 Pipeline not Connected to Electrical Grounding System

Fig. 1 shows the plan view of the common corridor of a transmission line and a pipeline. Note that the separation distances between the phase conductor, the overhead ground wire, and the pipeline are enlarged in order to show the system clearly. Fig. 2 shows a cross-section of the common corridor. The transmission line and pipeline are parallel for 11.2 km. The overhead ground wire is 19#8 Alumoweld. The radius of the steel pipe is 22 cm and its wall thickness is 2 cm. The pipe is coated with a coating resistively of 20,000,000 ohm-m and a coating thickness of 5 mm. The type of phase conductor will not affect the computation results because current sources are specified in the model.

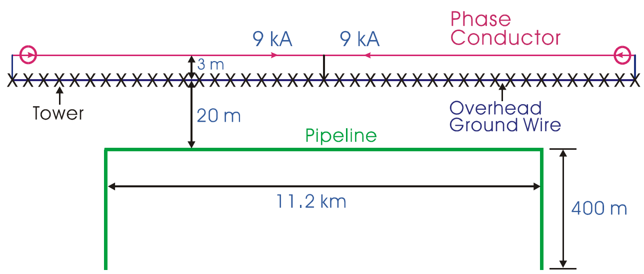

Fig. 1. Plan view of the corridor shared by a transmission line and a pipeline.

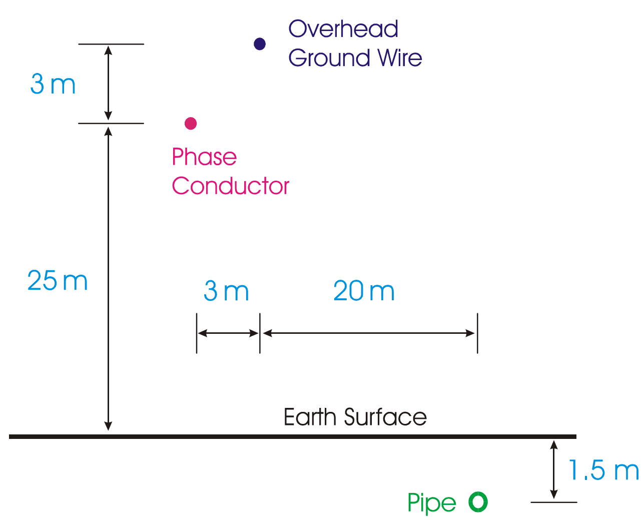

Fig. 2. Cross-section of the corridor shared by a transmission line and a pipeline.

Let us consider a fault occurring at the middle point of the parallelism and assume that the fault currents flowing in the phase conductors from both directions are 9 kA. The pipeline in this example is not connected to the grounding systems or tower footings of the electrical network. The objective is to compute the pipeline coating stress voltage.

When the conventional circuit method is used, line parameters such as longitudinal impedances and mutual impedances as well as pipeline coating resistances have to be calculated first. The parameter calculations are based on [5-6]. By solving the circuit model using the double-elimination method [7-8], the induced pipeline potential can be obtained. This induced potential is the inductive component of the coating stress voltage. To compute the conductive component, a grounding model is built, in which only the pipeline and the tower footings are modeled. The tower footings are energized using the currents computed when solving the circuit model. The pipeline is unenergized. The grounding model can be solved using the software package described in [9]. The difference between the pipe potential and the earth potential at the surface of the coating is the conductive component of the coating stress voltage. The total coating stress voltage can be obtained by adding up the inductive and conductive components, taking into account the phase angles. Fig. 3 shows the induced pipeline potential (inductive components) and earth potential (conductive component) of the coating stress voltage.

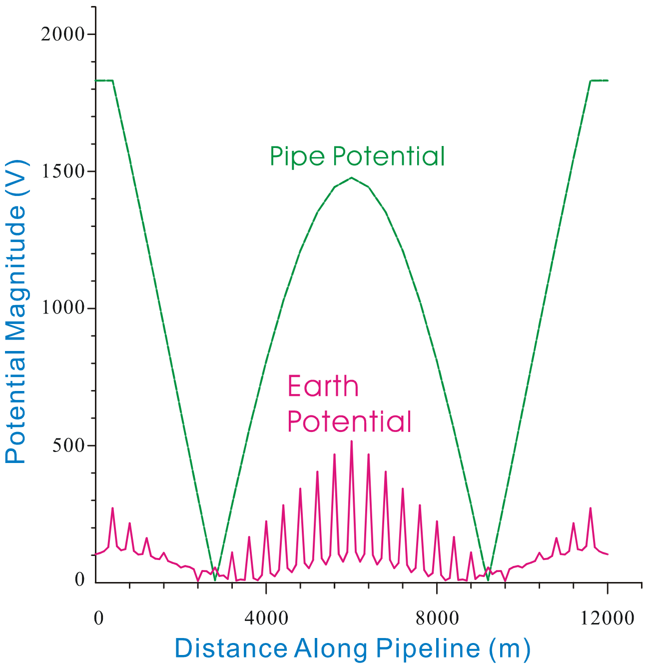

Fig. 3. Pipeline potential and earth potential computed using the conventional circuit method (CCM) followed by a grounding analysis.

In the new circuit method, the main difference is in the grounding model. The pipeline is now energized using the EMF values computed when solving the circuit model. Since these EMF values are responsible for producing the induced potentials on the pipeline in the circuit model, in effect, the inductive component is embedded now in this new grounding model. Therefore, the results from this grounding model can produce the total coating stress voltage.

In the EFM analysis, a conductor network is build which includes the pipeline, the phase conductor, and the neutral wire together with the tower footings. Solving this conductor network using the software package described in [9] leads to the total coating stress voltage in one step. This is because that the field method is based on exact electromagnetic field theory. The inductive and conductive components need not be considered separately as in the CCM.

Fig. 4 shows the total coating stress voltages computed using the CCM, the new circuit method, and the EFM. The results are in excellent agreement. It can be seen from the computation results in this example that there is no noticeable difference between the new circuit method and the CCM when the pipeline is not connected to grounding systems or to tower groundings and the pipeline is well coated.

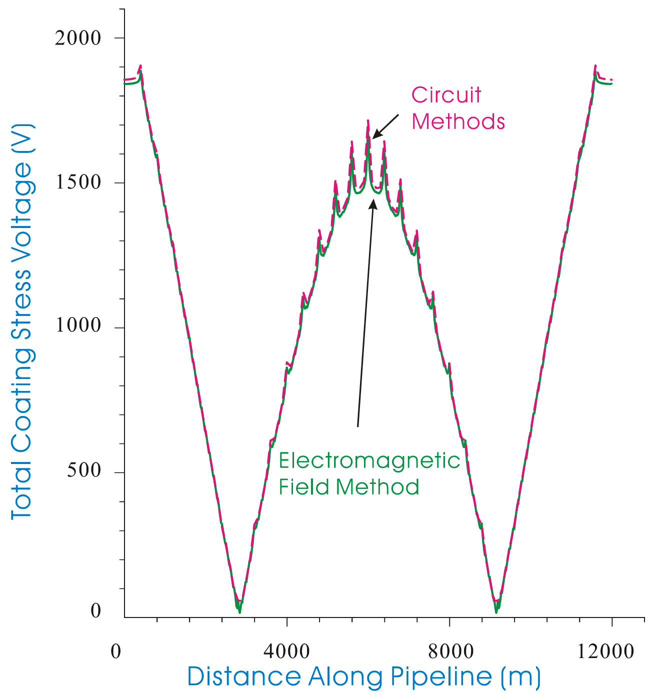

Fig. 4. Total coating stress voltage computed using the circuit methods and the electromagnetic field method.

3.2 Pipeline Connected to Electrical Grounding Systems

Figs. 5 and 6 show the plan view and a cross-section of the corridor shared by a transmission line and a pipeline. The pipeline is connected to the grounding grid at the right end of the transmission line. The 16” steel pipe has a wall thickness of 1 cm. It is coated with a coating resistivity of

19,580,000 ohm-m and a coating thickness of 1.27 mm. The overhead ground wire is made of steel with a radius of 1 cm. The tower footing is a single rod with a radius of 0.01m and a length of 2 m. When buried in a 100 ohm-m soil, it has a ground resistance of 45.26 ohms. Both the grounding grids shown in Fig. 5 are 50 m by 50 m with 4 meshes, buried at 0.5 m deep. The right grounding grid has a 20 m long rod at one of its corners. The computed ground resistances of the left and right grids are 1.11 ohms and 1.05 ohms in a 100 ohm-m soil, respectively.

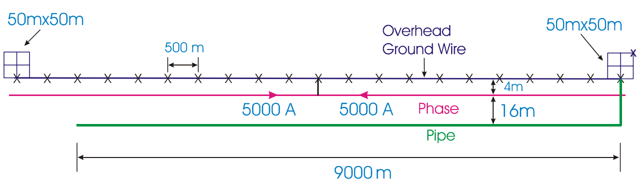

Fig. 5. Plan view of the common corridor shared by a transmission line and a pipeline connected to a grounding grid of the transmission line system.

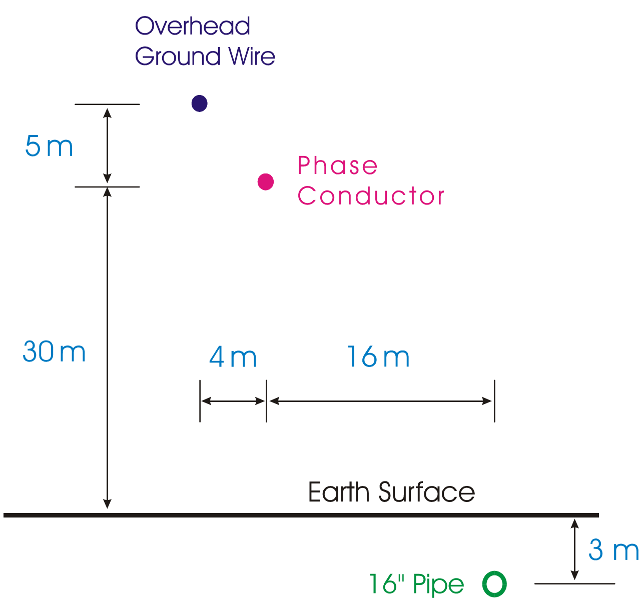

Fig. 6. Cross-section of the common corridor shared by a transmission line and a pipeline connected to a grounding grid of the transmission line system.

A circuit model as shown in Fig. 7 is built, corresponding to the common corridor system shown in Figs. 5 and 6. Note that the pipe shunt impedance, R_p in Fig. 7 has a negative imaginary part, which is due to the capacitance of the coating. After solving the circuit model, the pipeline potential is obtained. Note that the pipeline potential here is not only due to the magnetic coupling between the pipeline and the transmission line but also due to the connection of the pipeline to the right end grounding grid. If this pipeline potential is taken as the inductive component of the coating stress voltage and a similar grounding analysis using the CCM as in the above example is used to obtain the conductive component, the results will not be valid because conduction effects due to the connection to the grounding grid are considered twice. This problem cannot be easily solved using the CCM as shown in the above example. However, the new circuit method can be easily applied to this situation to obtain accurate results. In this case, the grounding model includes tower footings, the grounding grids, and the pipeline which is connected to the right end grounding grid. The tower footings and the grounding grids are energized using the currents computed from the circuit model while the pipeline is energized using the EMF values computed from the circuit model. It is easy to see that this grounding model will produce the total coating stress voltage because both the induction and conduction effects have been taken into account in the model.

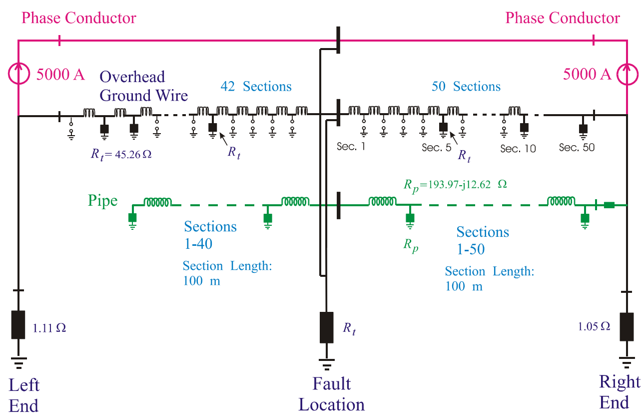

Fig. 7. Circuit model for the common corridor shared by a transmission line and a pipeline.

The EFM is also used to solve this problem. Fig. 8 shows the pipe potential from the EFM and the new circuit method. It can be seen that the values of the potential at the right end of the curve are very close for both methods. This is because the potential at this location is fixed by the grounding grid at the right end and both methods give similar values. At other locations the difference is larger. This is mainly due to the fact that the induction effect of the circuit method is usually overestimated slightly. Fig. 9 shows the earth potentials along the pipeline computed using the EFM and the new circuit method. The results are almost identical. Fig. 10 shows the total coating stress voltage computed using both the electromagnetic field method and the new circuit method. The results are in good agreement, as expected. In the new circuit method, the total coating stress voltage can be directly obtained when the grounding analysis is completed with the EMF values included in the analysis, thereby eliminating the tedious procedure of combing the inductive component and conductive component. This problem can also be solved by EFM as described above. However, for very long common corridor with many transmission line circuits, the new circuit method is more efficient.

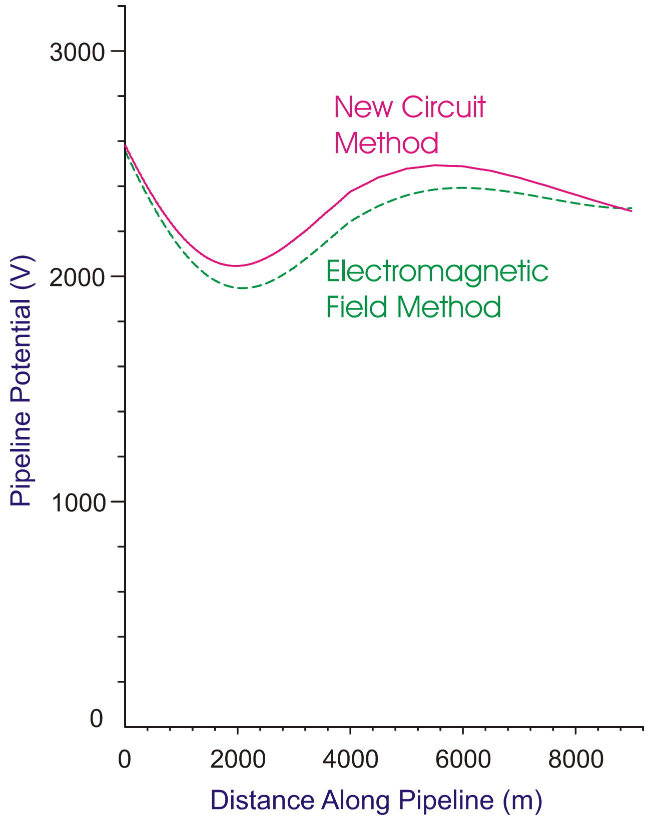

Fig. 8. Pipeline potentials computed using the electromagnetic field method and the new circuit method.

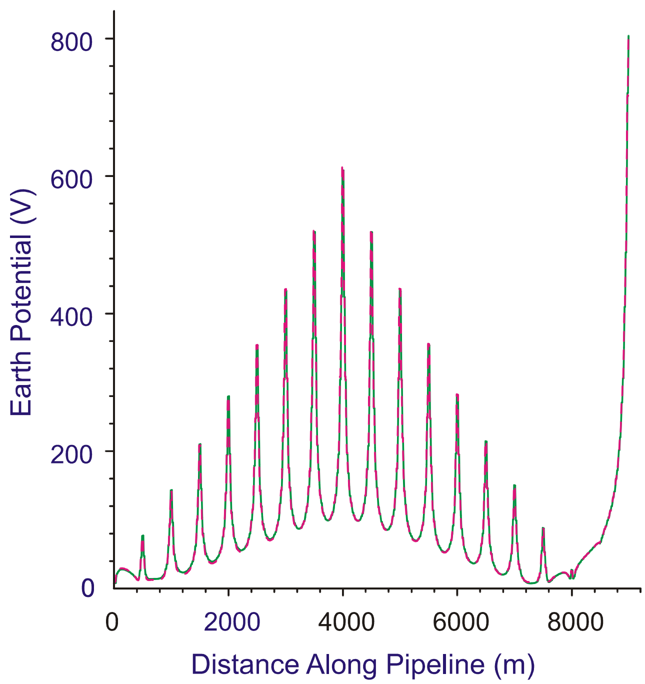

Fig. 9. Earth potentials along the pipeline computed using the electromagnetic field method and the new circuit method.

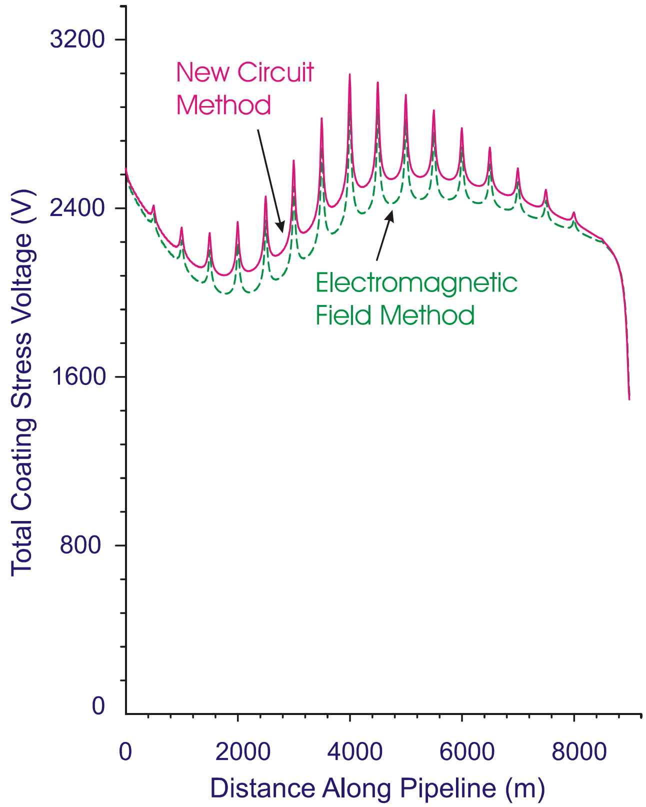

Fig. 10. Total coating stress voltages computed using the electromagnetic field method and the new circuit method.

4. Conclusions

A new circuit method for analyzing interference problems is introduced, which can be used to compute the total interference level efficiently and accurately. Results obtained using the conventional circuit method and the electromagnetic field method are presented and compared with those obtained using the new circuit method for practical examples. It is shown that the new circuit method can be applied to problems which cannot be solved using the conventional circuit method. The new method can be used in cases involving long common corridors with a large number of transmission line circuits, which are difficult to handle using the electromagnetic field method.

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