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Comparative Simulation of Pipeline Potential nearby Cables and Power Lines-practical case study

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Abstract

Electromagnetic interference effects caused by electric power lines or cables on neighboring metallic utilities such as water, gas or oil pipelines became a major concern due to significant increase in the load and short circuit current levels needed to satisfy the load requirements. Another reason for increased interference levels originates from the environmental concerns, which impose on various utilities the obligation to share common corridors. This paper presents a comparison between the pipeline potential caused by overhead transmission lines and electric cables on a practical system. The results reveal that the electric cables produce lower voltage on the pipeline compared with the overhead transmission lines during both steady-state and fault conditions. Moreover, a mitigation system has been designed to reduce the pipeline voltage to satisfactory level during fault condition according to ANSI/IEEE Standard 80 safety criteria. The design was based on the computed voltage profile along the pipeline.

The results of the computer model for the power lines were verified experimentally. Good correlation was achieved between experimental and simulation results.

Keywords: *Pipeline Potential, Transmission Lines, Cable, Mitigation*

1. Introduction

Oil/gas/water pipelines and overhead power lines/cables share the same right-of-way in some areas. As a consequence, the pipeline can incur high induced voltages and currents due to AC interference. Magnetic and electric fields surrounding the power system in the air and soil energize the pipeline. The induced voltage on the pipeline can be dangerous and potentially life-threatening for people when touching the pipeline or appurtenances and can cause pipeline corrosion or damage the cathodic protection system [1-8]. To reduce the effects of the AC interference levels to acceptable limits according to ANSI/IEEE Standards 80 [9], a mitigation system should be designed [6].

The likelihood of interference increases with increasing overhead-line current, with increasing quality of the coating on the pipeline, with increasing soil resistivity, and with the length of pipeline parallel to and close to the transmission lines. The electromagnetic interference between a power system network and neighboring pipeline has been traditionally divided into three categories: capacitive (electrostatic), conductive (resistive) and inductive (magnetic) coupling. The first is the capacitive coupling, which is generated by electric field, influences only pipeline above ground, having no path to ground. The pipe picks up a voltage relative to soil that is proportional to the transmission line voltage. The second is the conductive interference, which occurs during lightning strikes or a phase-to-ground fault. When this is occurred, a large voltage cone is created around the grounding system; as a result a voltage can get onto the pipeline through the pipe coating defects. The third is the inductive interference, which is generated by the magnetic field and present during both normal operating and fault conditions, where the maximum coupling occurs when the pipe is placed parallel with three-phase transmission lines. In normal operating conditions, the balance of the three-phase currents causes insignificant interference effect. In this case only a small voltage is induced, due to the geometrical asymmetry of the electromagnetic field. On the other hand the electromagnetic AC interference due to single phase to ground fault is substantial.

In this paper a practical case was selected in order to make comparison between the effects of using overhead transmission lines and cables on the value of the pipeline potential during both steady-state and transient conditions. Moreover, based on the computed voltage profile along the axial length of the pipeline a mitigation system has been designed. The potential level on the mitigated pipeline has been reduced to a satisfactory level in according to ANSI/IEEE standard 80 criteria.

An experimental reduced-scale rig was also built to verify the simulation results for the power lines case. A Good correlation between the experimental and software based simulated results was obtained which validates the modeling approach of coupling between power transmission line and pipeline.

2. System Model Parameters

The system layout is shown in Fig. 1. It consists of transmission lines, cable and a neighboring pipeline. The total length of the transmission lines is 2694m and the length of the cable is 2139m. The pipeline is placed in parallel with transmission lines and the cable, and it is buried at a depth of 0.5m. It can be seen that the length of parallelisms is 3132m and the distance between the over head transmission line and the pipeline is varying.

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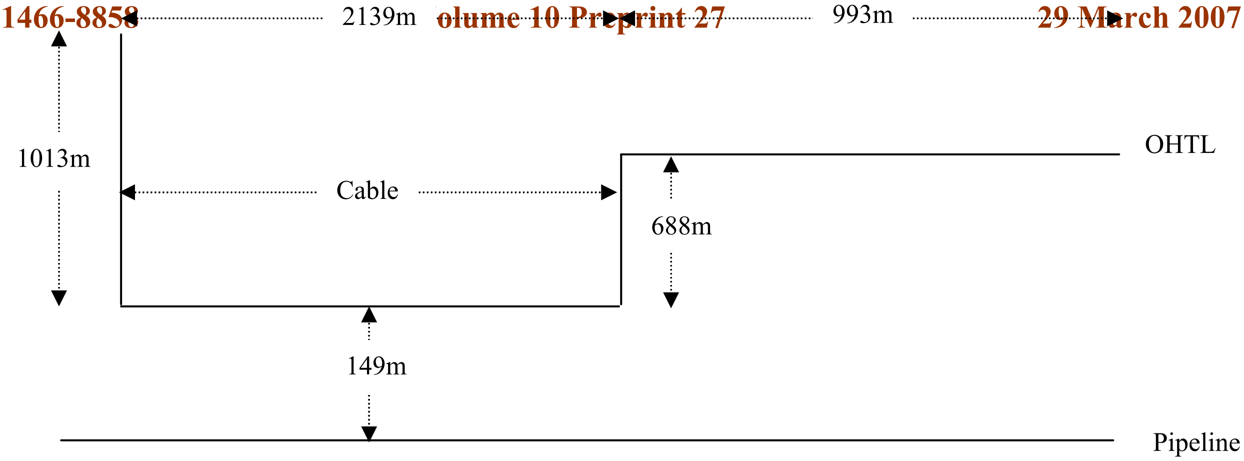

Fig. 1: System layout

The investigation reported in this paper is based on a state-of-the-art commercial computer aided-design tool, the theory of which is described in [10-11]. In particular, the analysis of electromagnetic interference between the 132kV overhead power lines/cable and the neighboring gas/oil/water pipelines has been carried using the well-known CDEGS software [12].

The following is a list of parameter settings of the computer model used in this study:

48-inch Gas Pipeline

Coating Resistivity: 15665 $\Omega.m$

Coating thickness: 0.0037m

Outer Diameter: *1.2192 m*

Inner Diameter: *1.196 m*

Wall thickness: *0.0232m*

Burial depth: *2 m*

Relative Resistivity: *17* (with respect to annealed copper).

Relative permeability: *250* (with respect to free space).

Grounding: *None*

Overhead Transmission line

AAAC (Twin) YEW 132 kV

G.M.R: *1.107 cm*

Conductor outer radius: *1.421 cm*

Outer strand radius: *0.203 cm*

Number of strands: *37*

Fault current (phase-to-ground fault), I_f: 3.9 KA.

Steady-state current, I_a: 629 A

Optical ground wire

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Outer radius: 7.05mm

Dc resistance: 0.354 ohm/km

<u>Cable</u>

Cable outer radius: 83 mm

<u>System</u>

Length of parallelism: *3.132 km*

Soil Resistivity, ρ: 50 $\Omega.m$

Horizontal Separation distance, d: 149 m for length of parallelism of 2.139 km and 837m for length of parallelism of 993m.

<u>Mitigation System</u>

Gradient control wire: Zinc ribbon with diamond-shaped 12.7x14.28 mm (1/2 x9/6 inch).

3. Steady-State Conditions

3.1 Overhead Transmission Lines

The right of way was modeled under worst-case steady-state condition with maximum current of 629 A per phase. The induced potential on the pipeline reaches 6.5 volts when overhead transmission line is used, as shown in Fig. 2. The maximum acceptable touch voltage according to ANSI/IEEE Standard 80 safety criteria is *15-V* under worst-case emergency load conditions. All personnel working on right-of-way need to be aware that under fault conditions this voltage will be greatly exceeded. NACE Standard RP-0177-95 recommended a 15-V touch voltage limit, based on the let-go- current threshold for most men. It should be noted that the software generates a voltage profile along the axial length of the pipeline, in which the pipeline is divided into a number of sections and the length of each section is set to 100 m.

The results obtained using the software have been verified by the following formula reported in [13] and good agreement has been obtained.

$$E = Z_m I_f \tag{1}$$

where

E :*The induced voltage on pipeline*, V/km

I_f :*The fault current*, A

The mutual impedance between the conductor and the pipeline is:

$$Z_m = k \ln \frac{D''}{D'} \tag{2}$$

where

$$k = j*(f\ \mu_0)$$

$$D'' = \sqrt{(h + h' + 2p)^2 + d^2}$$

$$D' = \sqrt{(h - h')^2 + d^2}$$

$$p = \sqrt{\frac{\rho}{j*(2\pi f \mu_0)}}$$

f : *Frequency, Hz*

$\mu_0 = 4\pi * 10^{-7}$ *H / m, the free space permeability*

ρ : *The soil resistivity ,Ω.m*

h: The vertical distance between each phase power line and pipeline, m.

h′: The vertical distance between the pipeline and ground, m.

d: The horizontal distance from current carrying conductor to the pipe, m.

It should be noted that the incremental voltage induced into a parallel conductor by the power line current is analytically equivalent to an electric field intensity that is parallel to the conductor [14].

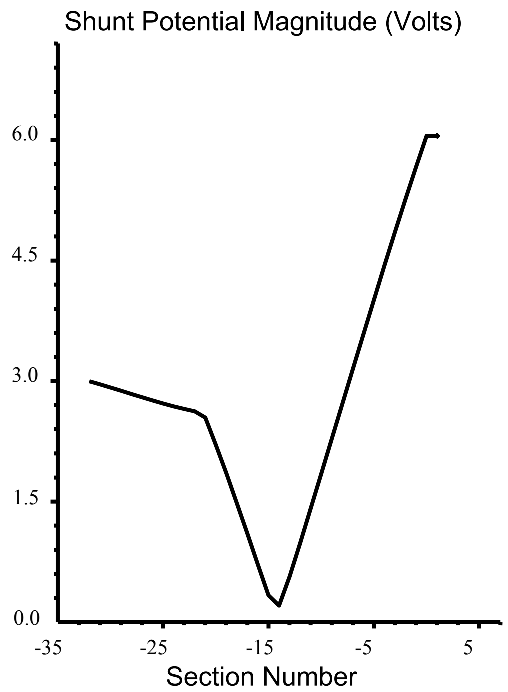

Fig. 2: Pipeline Potential along the axial length of the pipeline for ρ =50Ω.m, I_a =629 A when using overhead transmission lines

A comparison between the analytical approach and the model reveals that they are in a good agreement. The analytical approach, however, yields slightly higher results as shown in Fig. 3. It should be noted that the analytical approach reported in [13] neglects the current in the other two phases during the single line to ground fault.

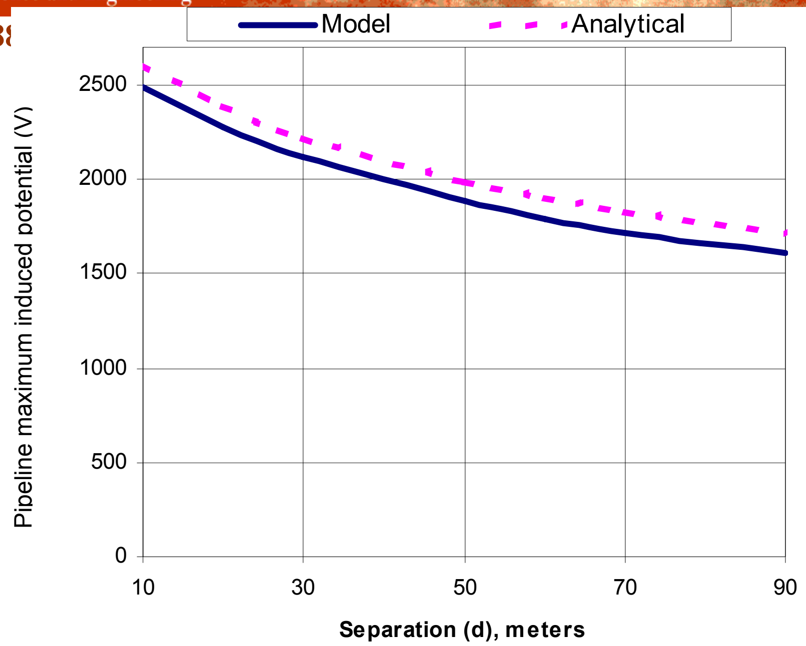

Fig. 3: Pipeline maximum induced potential, due to inductive coupling under fault condition: I_f = 2000A, 132 kV, ρ=1000 Ω.m using analytical and computer model.

3.2 Underground electric Cable

The induced potential on the pipeline is presented in Fig. 4, which is reduced to less than 3 volts throughout the right of way. This reduction could be explained by the fact that the three phases are very close to each other, when cable is used, then the cancellation of electromagnetic field will be more as a result the induced potential will be small.

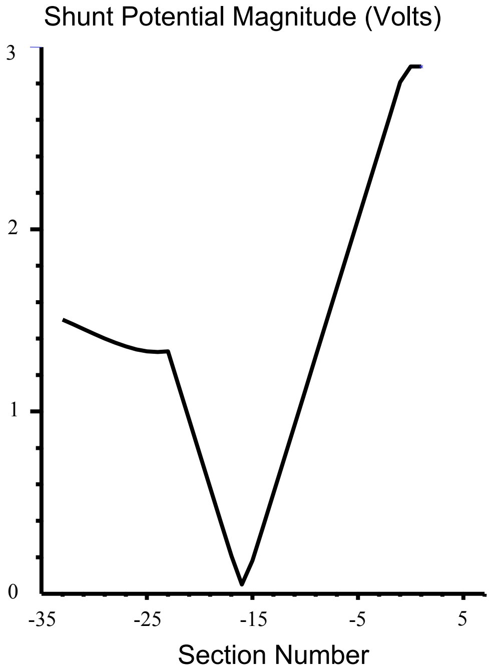

Fig. 4: Pipeline Potential along the axial length of the pipeline for ρ =50Ω.m, I_a =629 A when using electric cable

4. Transient Conditions

4.1 Overhead Transmission Lines

Figure 5 shows the profile of the maximum induced potential on the pipeline during single line to ground fault. Notes that there is no problems regarding the pipeline coating stress voltage because the pipeline coating can withstand coating stress voltage up to 3000 V. On the contrary, the voltage does exceed the ANSI/IEEE standard 80 touch voltage limits. To reduce the touch potential, along the whole length of the pipeline, to a safe limit according to IEEE standard a mitigation system should to be designed.

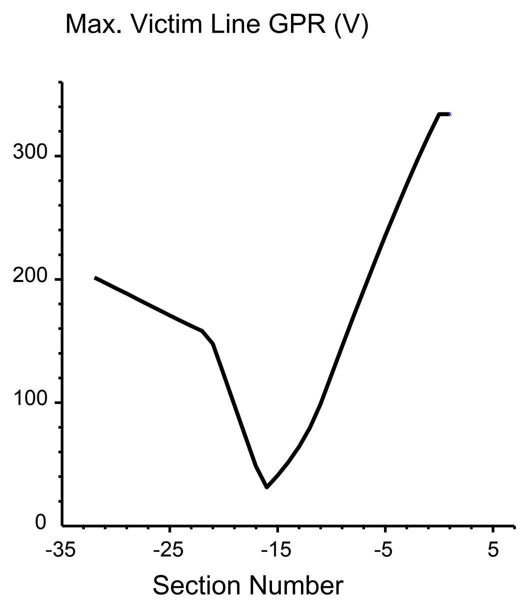

Fig. 5: The maximum Potential along the axial length of the pipeline for ρ =50Ω.m, I_f =3.9 kA when using overhead transmission lines

4.2 Underground electric Cable

Under single phase-to-ground fault, with fault duration of 0.3 s soil resistivity of 50 Ω.m, the permissible "safe touch voltage", according to ANSI/IEEE standard is 228.3 V [9]. The maximum potential along the pipeline is presented in Fig. 6 which does not exceed the ANSI/IEEE standard 80 touch voltage limits. Therefore, mitigation system is not required if electric cable is used to supply the required power to the load. These potentials also represent the pipeline coating stress and touch voltages, given the high resistance of the pipeline coating.

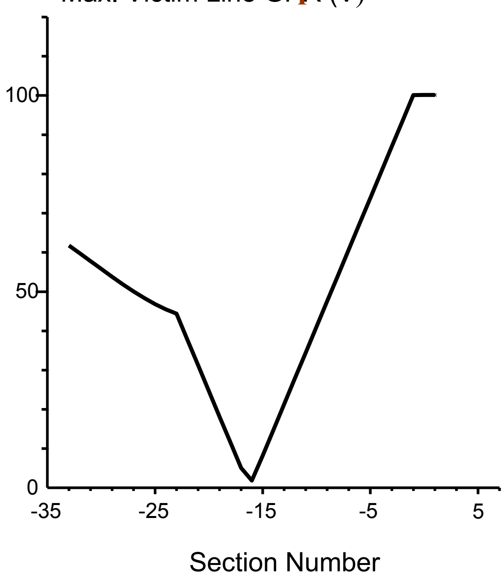

Fig. 6: The maximum Potential along the axial length of the pipeline for ρ =50Ω.m, I_f =3.9 kA when using electric cable

5. Mitigation

To reduce the touch potential, along the whole length of the pipeline, to a safe limit according to IEEE standard for the case of the overhead transmission line a mitigation system has to be used. The mitigation system will consist of a zinc ribbon buried with the pipeline and connected to it at regular intervals. The wire should be connected to the pipeline at two strategic locations; the beginning and end of the proposed 132kV overhead lines.

After applying a mitigation wire of 200m at both ends of the pipeline, the induced potential is reduced to 185 V as presented in Fig. 7, which satisfy the safe touch voltage standard.

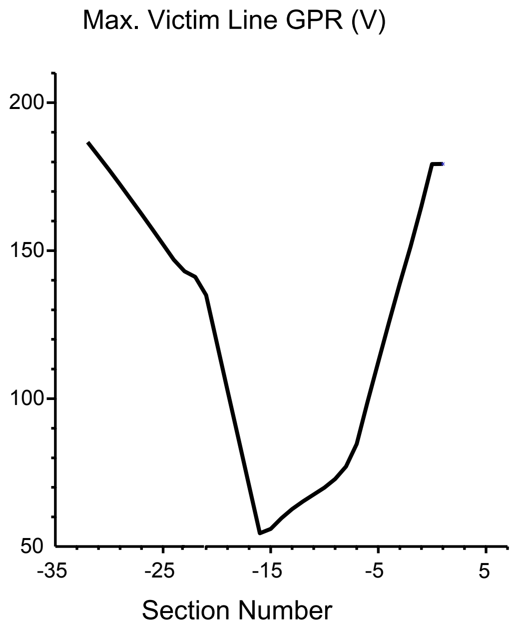

Fig. 7: The maximum Potential along the axial length of the pipeline for ρ =50Ω.m, I_f =3.9 kA when using electric cable with mitigation

6. Model Verification

The induced voltage due to overhead transmission line was validated, for the capacitive component, by comparing the model with the experimental results. Fig. 8 shows the experimental setup of the reduced scale test rig used to investigate the electromagnetic coupling between the energized wire and a steel pipeline [4]. A copper conductor with a radius of 1mm is used in the experiment. A steel pipe having outer diameter of 1.27cm, inner diameter of 1.03cm and 2m long is also used in the investigation. In this test, both the pipe height z and the wire height h are kept constant at 3cm and 50cm respectively. A single-phase AC voltage (V_w) is applied to the conductor and varied up to 40 kV. Moreover, the horizontal coordinate of the pipe from the center of symmetry underneath the conductor (lateral distance) is fixed to zero. An aluminum plate was used to model the soil resistivity. To eliminate the end effects of the conductor, the aluminum plate is divided into three separate sections; the current signal is picked up from the middle section while the two other sections are earthed. Simultaneous measuring and displaying of both the applied voltage to the conductor (V_w) and the pipe-induced voltage (V_p) are recorded.

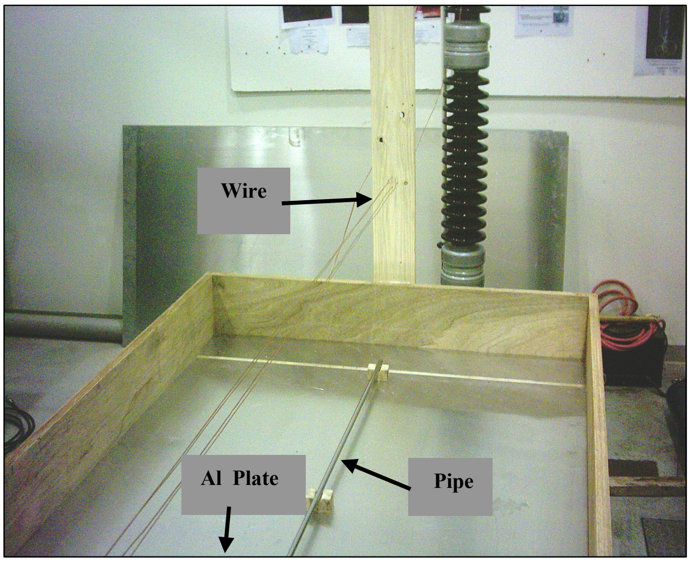

Fig. 8: Picture of the test rig.

Fig. 9 presents the relationship between the applied voltage and the relative pipeline voltage for both the test rig and the model. It is clear from the Fig. 9 that increasing the applied voltage will increase the pipeline induced voltage due to the effect of capacitive coupling. For applied voltages less than the corona inception voltage, excellent correlation is achieved between the measured and simulated results. However, at voltages higher than corona inception voltage, the measured results are higher compared to the simulated results which indicate that the model did not consider the effects of corona and space charge. However, taking the corona effects into account in the simulation is insignificant from the practical point of view because the rated voltage of overhead power lines is normally lower than the corona inception voltage.

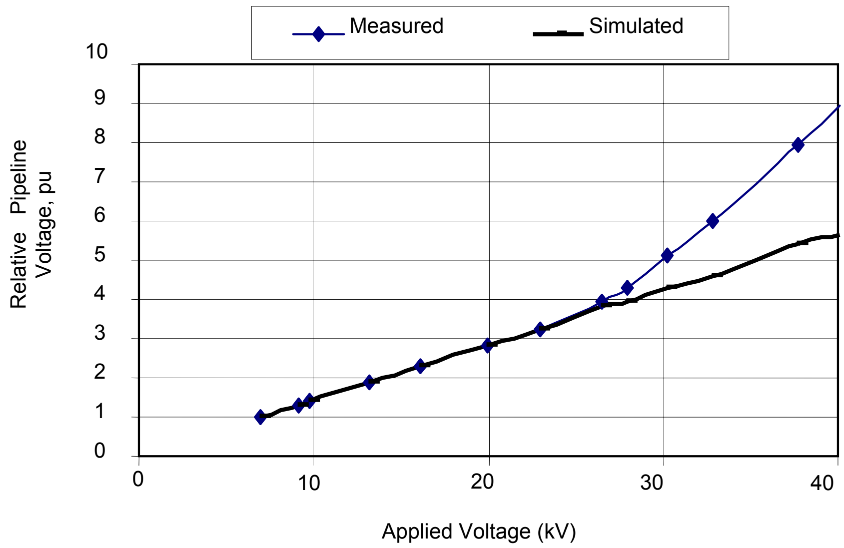

Fig. 9: Relative pipeline voltage versus applied voltage.

7. Conclusions

Electromagnetic interference caused by 132-kV overhead transmission lines/cable on neighboring parallel pipeline has been analyzed under both steady-state and single-phase-to-ground fault using computer software for a practical system. The model developed can predict the level of the induced potential on the pipeline. The results have shown that the induced potentials on the pipeline, when electric cable is used, is within the acceptable touch voltage limits (110 V during line-to-ground fault) and are exceeding the acceptable limits determined in accordance to ANSI/IEEE Standard 80 when overhead transmission lines are used (350 V during line-to-ground fault). The model was verified by using well known-equation.

The study shows that the mitigation proposed in this study, when overhead transmission lines are used, reduces the pipeline potential to acceptable levels (185 V) during the fault conditions. The proposed ac mitigation is the connecting of zinc ribbon anode to the pipeline where the pipeline potential is high.

An experimental reduced-scale rig was also built to verify the simulation results. A Good correlation between the experimental and software based simulated results was obtained which validates the modeling approach of coupling between power transmission line and pipeline.

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