Managing Pipeline Integrity by Mitigating Alternating Current Interference

L. Bortels and J. Parlongue, *Elsyca N.V., Leuven, Belgium*
Wolfgang Fieltsch and Sorin M. Segall,
Corrosion Service Co., Ltd., Markham, Ontario, Canada

The main concerns in sharing a corridor between pipelines and power transmission lines are personnel safety, corrosion, and coating damage. High-voltage, alternating current-induced corrosion is a significant threat to pipeline integrity. This article describes a simulation software that models both resistive and inductive interference and presents practical results of simulations on two different configurations.

Increased difficulty in obtaining utility rights-of-way (ROW) has brought pipelines into close proximity with electric power transmission systems. Any metallic object subjected to an alternating electromagnetic field will exhibit an induced voltage. Power conductor faults-to-ground can cause substantial fault currents in an underground structure.[1-2]

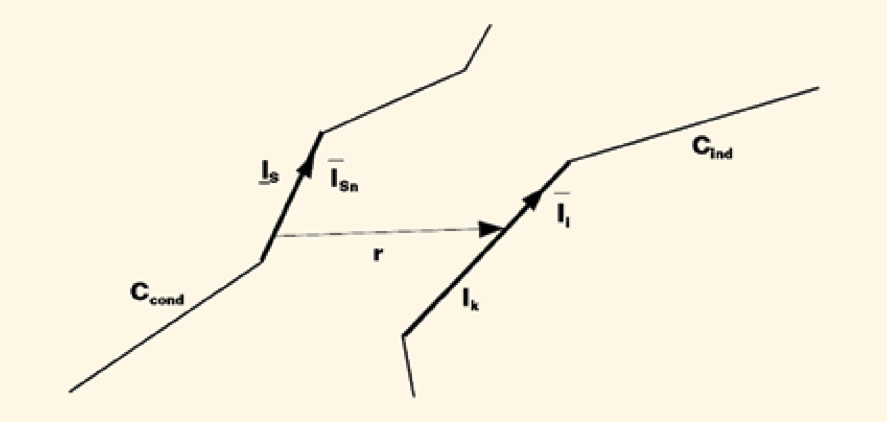
There are three methods that can induce alternating currents (AC) and voltages on metallic structures near AC power lines. The first is electrostatic coupling, where the structure acts as one side of a capacitor with respect to the ground. This is of concern only when the structure is above grade. The second is electromagnetic induction, which occurs when the structure is either above or below ground. In this case, the structure acts as the single-turn secondary of an air-core transformer in which the power line is the primary component. The final method is resistive coupling caused by fault currents from AC power towers that flow on and off an underground structure.

Stray currents from these induced voltages can cause corrosion, although the amount of metal loss is less than an equivalent amount of direct current (DC). AC stray current is often large—hundreds of amperes under electromagnetic induction and thousands of amperes during power line faults. High current and voltage levels can produce a shock hazard for personnel and can damage the structure (coating, etc.) and related equipment, such as cathodic protection (CP) components.

NACE International SP0177-2007[3] states that steady-state induced potentials in excess of 15 V should be considered hazardous and steps should be taken to reduce the voltage. SP0177-2007 also provides guidelines for maximum allowable touch and step potentials and coating stress in case of ground faults.

A software suite for AC predictive and mitigation techniques has been developed that allows the modeling of any number of pipelines, high-voltage transmission lines, and bonds without any restriction on the complexity of the geometry. The global positioning system (GPS) or flat coordinates from pipelines and high-voltage transmission lines can be used directly as input for the simulations, as well as varying dimensions and electrical parameters along the ROW.

FIGURE 1



Division of source and victim wire in piece-wise linear segments.

TABLE 1

Powerline parameters

Parameter	Crossing #1	Notes
Pole type	Wood	Steel cross arms
Maximum phase-to-ground fault current	2,300 A	—
Fault duration	350 ms	—
Pole grounding	Typically 1-in by 3/4-in by 6-ft (25-mm by 19-mm by 1.8-m) ground rod	Pole T106, has a 1 by 20-ft (0.3 by 6.1-m) concrete foundation
Shield wire	1 by 3/8-in (25 by 9-mm) Grade 220 steel wire	—
Average span	145 m	—

Simulation Software

Fault-to-Earth (Resistive) Interference

To properly describe the potential and current density distributions that arise from fault-to-earth situations, the model links the "external" world—the soil—with the "internal" world—the metallic conductor of the pipe or the grounding of a tower.

By modeling the complete half-space or insulating effect of the earth, the model automatically takes into account the interference among all structures (pipelines, anodes, tracks, tower grounding, gradient control mat, etc.) that are included in the model. In addition, any two points in the complete configuration (pipelines, anodes, grounding rods, etc.) can be connected to each other either by a direct or resistive bond. This allows modeling of the effect of compensation currents between pipeline sections at different potentials. The effect of structures such as pipelines or powerlines that are "electrically long" can be modeled by terminating sections with a characteristic impedance.

The software is able to model double-layer configurations and non-uniform grounding resistance for poles/towers and calculates the ground potential rise (GPR) and touch potential along the complete pipeline network. Pipeline dimensions and near-pipeline soil resistivity can be applied on each section of the model to take into account local changes along the developed length of the network. This allows modeling of the coating stress (the difference between the pipeline voltage and potential near the pipe just outside the coating) by taking into account local coating resistance variations.

Steady-State (Inductive) Interference

The key point in modeling the steady-state (inductive) interference is the correct calculation of the induced electromagnetic force (EMF). In the software described here, the direction of the pipeline with respect to the transmission line(s) is automatically taken into account.

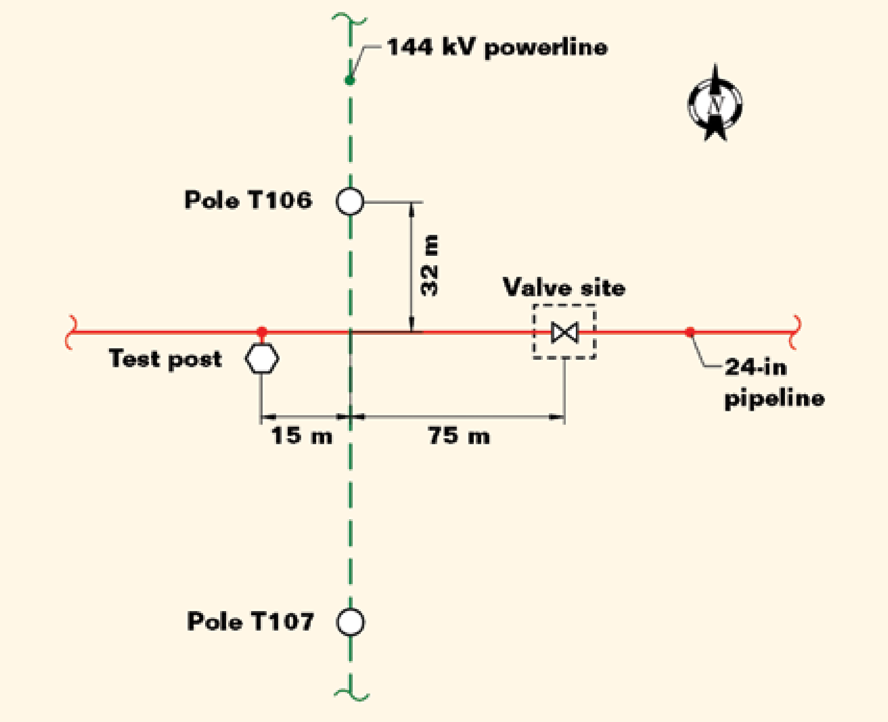
Calculation of the EMF

Figure 1 presents a "source wire" (part of the transmission line) and a "victim wire" (part of the pipeline), both shown as a collection of segments that represents successive sections of the model.

The formula for the induced EMF is a function of the product between the directions of both the source and victim wire. This implies that the position of the pipeline, with respect to the transmission line, is automatically taken into account and subdivision of the pipeline in sections parallel or nonparallel to the transmission line is not needed.

The software considers each individual wire of the powerline network, thus allowing an unlimited number of different tower configurations to be modeled while automatically taking into account phase

FIGURE 2



Pipeline/powerline crossing configuration.

TABLE 2

Ground potential rise on 1 by 1 m^2

Location	Minimal (V)	Maximal (V)
Valve site	1,525	1,555
Crossing	2,915	3,050
Test post	2,695	2,845

TABLE 3

Coating stress

Location	Coating Stress (V)
Valve site	1,535
Crossing	2,980
Test post	2,760

transpositions along the trajectory. Geometrical and electrical parameters can vary along the ROW, which implies that the local sag between two individual towers can be taken into account.

Calculation of the Induced Pipeline Voltage and Current

With the obtained values for the EMF, as specified earlier, the induced voltages and currents are then calculated by solving the well-known transmission line model. This is done using a numerical technique that allows one to specify the pipeline parameters (diameter, coating, soil resistivity, etc.) for each individual section of the pipeline.

The work is completed by applying the proper boundary conditions involving the implementation of (resistive) bonds, groundings, and characteristic impedances. Resistive bonds are modeled as a wire with a known impedance that is placed between two nodal points. Grounding and characteristic impedances can be seen as special bonds between a nodal point of the pipeline and the non-influenced area of the pipeline. Characteristic impedances can be placed at the beginning and/or end of a pipeline to model electrically long pipelines.

More details on the modeling of fault and steady-state interference using the software described here can be found elsewhere.[4-8]

Examples

Pipeline and Powerline Crossing in Two-Layer, Very High-Resistivity Soil

The first example is related to a study conducted in Canada. The data were modified for confidentiality, and the original analytical calculations were redone with the modified data. The results were used to validate the program outputs. The program outputs for this application closely matched the results of the calculations based on the proprietary analytical formulas developed.

The application covers the crossing between a new 144-kV powerline and an existing 24-in (609-mm) pipeline. Table 1 shows the relevant powerline parameters.

The pipeline, installed in 2008, has a fusion-bonded epoxy (FBE) coating with an estimated normalized conductance of 10 µS/m^2. The entire line is electrically continuous. There are isolation flanges at the two ends of the line, which are more than 100 km from the crossing. Therefore, the pipe is considered infinitely long electrically, both upstream and downstream of the crossing.

The distance between the pipeline and the closest pole (i.e., T106) is 32 m (Figure 2). The closest above-grade valve accessible to pipeline personnel is located 75 m downstream from the crossing. A test post is located 15 m upstream of the crossing. The closest groundbed is located more than 5 km from the crossing, therefore no DC interference was expected on the powerline poles. The soil resistivity measurements indicated a two-layer configuration. The 1.2-m thick upper layer has a resistivity of 2,000 Ω-m and the lower layer has an even higher resistivity of 6,000 Ω-m.

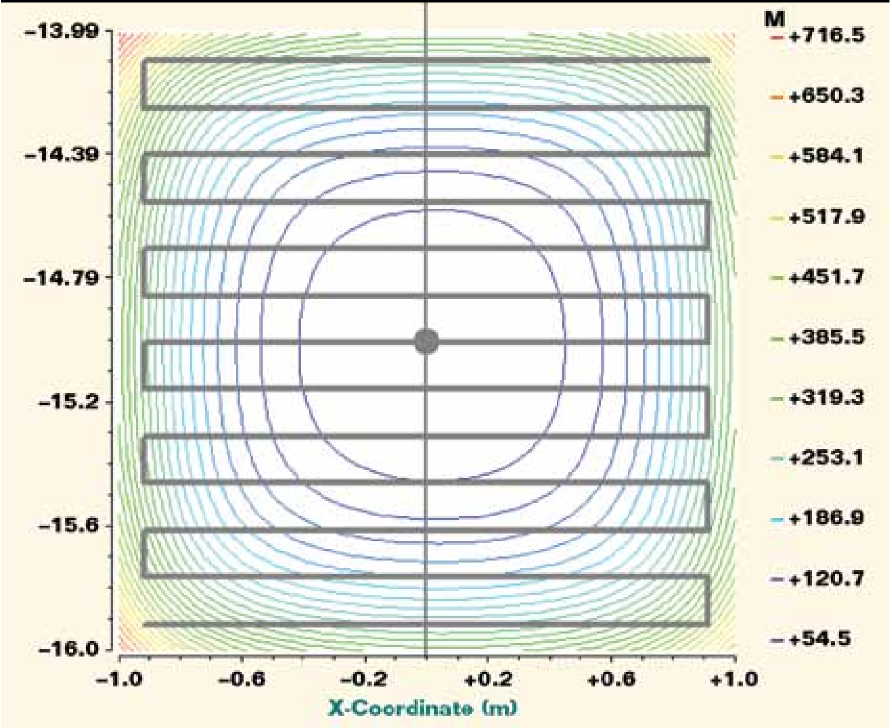
The complete configuration of this interference problem, with the exact location of the poles and dimensions of grounding rods, was entered in the software. The calculated grounding resistance for the wooden poles in the two-layer soil is 1,385 Ω. Pole T106 (steel with a concrete foundation) has a calculated grounding resistance of 390 Ω. The calculated current distribution in the electrical network formed by the shield wire and the poles for a phase-to-ground fault of 2,300 A at pole T106 showed that ~79.5 A leaks into the ground at pole T106, while ~1,025 A is going to remote poles. The GPR can be calculated at any location in the model. The highest GPR values (1,555 V) were found nearest to the faulted pole (T-106). Table 2 lists a summary of the minimum and maximum GPR values at the different location.

The transferred voltage to the pipeline (which is considered electrically infinitely long) is negligible. The resulting touch voltage at the valve station (~1,535 V) does exceed the maximum allowable touch voltage of 875 V, therefore a gradient control mat should be installed at the valve station per paragraph 5.2.3 of NACE Standard SP0177-2007. The touch potential at the test post (between 2,700 and 2,850 V) also exceeds the maximum allowable touch voltage (771 V). Either a gradient control mat should be installed or the test post should be upgraded to dead-front construction.

The software was used to calculate the effect of a standard gradient mat, 6 by 6 ft (1.82 by 1.82 m), buried at the test post 400 mm below grade. Figure 3 illustrates the calculated GPR at the test post on a 1 by 1 m^2 area. The highest GPR values (715 V) are found at the extremities of the square area. The average value of the GPR at a distance of 1 m from the test post is ~350 V, while the transferred voltage to the pipeline is 15 V. The maximum touch voltage after installation of the gradient mat (325 V) therefore stays far below the 771 V permissible limit.

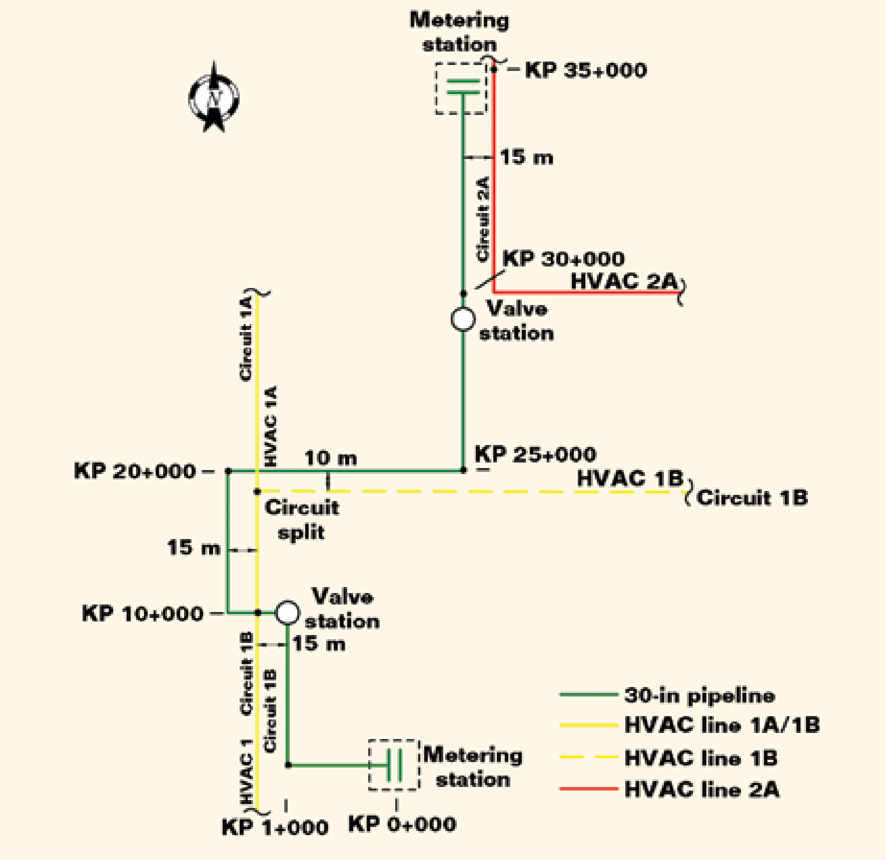
The permissible GPR limit was calculated after modeling the foot resistance in the two-layer soil. Since the size of the disk

FIGURE 3



Calculated ground potential rise at the test station, marked with dot.

FIGURE 4



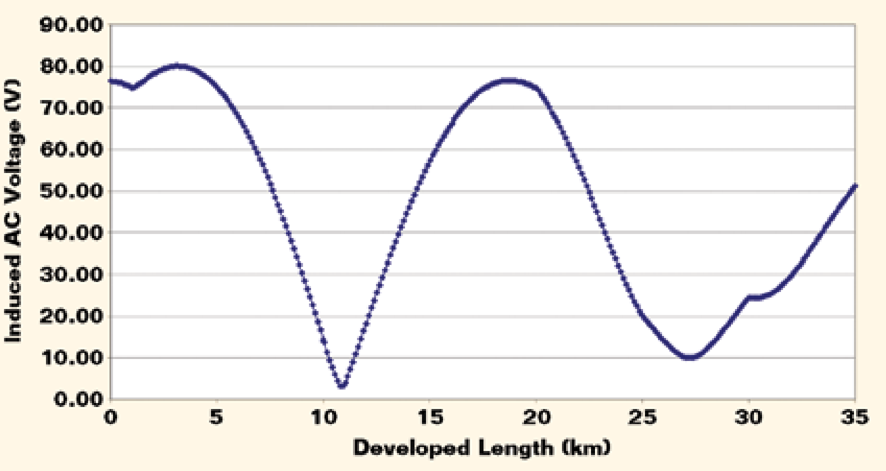
Pipeline/powerline configuration.

TABLE 4

Powerline data

Description	Line 1A/1B	Line 1B	Line 2A
Nominal line kV	345 kV	345 kV	138 kV
Pipeline chainage (km)	0.0 to 20.0	20.0 to 25.0	30.0 to 35.0
Tower type	Steel lattice	Steel lattice	Wood H-pole
Circuits	Double vertical	Single horizontal	Single horizontal
No. shield wires	2	1	2
Shield wire type	3/8-in EHSS	7/16-in EHSS	3/8-in EHSS
Height of shield wire **(units?)**	36	36	28
Dist. from center (shield wires) **(units?)**	5	1.5	3
Avg. height at structure **(units?)**	29/21.5/21.5	22.5/22.5/22.5	15/15/15
Avg. height sag **(units?)**	7.6	7.6	4.6
Distance from center **(units?)**	7/11/4	–7.6/0/–7.6	–4.5/0/–4.5
Phasing looking north (or east)	C A B A C B	A B C	A B C
Average distance between towers (m)	300	300	200
Transpositions in section	None	None	None
Maximum current (A)	900/900	900	500

FIGURE 5



Modeled induced AC voltages.

electrically representing the foot (80-mm radius) is very small with respect to the thickness of the first layer (1.2 m), the simulation demonstrated that the zone of influence of the disk is limited to the first layer only.

Table 3 presents a summary of the calculated coating stress along the section of the pipeline that is close to the faulted tower. The maximum coating stress (2,980 V at the crossing) is marginally below the 3,000 V limit specified in paragraph 4.13.2 of NACE Standard SP0177-2007.

Gathering Piping System in Powerline Corridors

The second example is loosely based on an AC study performed on a 30-in (762-mm) pipeline gathering system in the United States. The gathering system was situated in an urban area, and most of the piping was routed in existing powerline corridors. The pipeline, installed in 2009, has a FBE coating with an estimated coating resistance of 100 KΩ-m^2. The line starts in a station at KP 0, where it is isolated and ends in a metering station at KP 35. The pipeline is isolated from all stations with flanges. Figure 4 shows the complete pipeline/powerline configuration. Table 4 provides the powerline parameters.

The soil resistivity was found to be relatively uniform with respect to depth, so a single-layer soil configuration of 100 Ω-m was used in the model. The data were entered into the model and the steady-state induced voltages on the pipeline were calculated based on the maximum normal loading for safety of personnel. Figure 5 shows the results.

The steady-state induced pipeline voltages were well above the 15-V safe voltage recommended in NACE SP0177-2007 at above-grade or exposed pipe sections. Mitigation was entered into the model as discrete grounding (resistances), at the locations identified in Table 5.

The mitigated steady-state voltages (Figure 6) were reduced to below the 15-V safety limit for the entire length of the pipeline.

Conclusions

A simulation software suite has been presented that can model both resistive and inductive interference in ROWs with pipeline and power transmission networks of any complexity.

The model has been applied to two different configurations. The first covered the crossing between a new 144-kV powerline and an existing 24-in pipeline. The simulated values for the GPR, transferred voltage to pipeline, coating stress, and touch potentials under a phase-to-ground fault of 2,300 A have been shown, as has the effect of a standard gradient mat. The second case described a 30-in pipeline gathering system. The pipeline was influenced by three powerlines. The simulation indicated that the AC-induced voltages would exceed the safety limits and a mitigation system was designed and simulated to bring the AC induced voltages to below the 15-V safety limit.

References

1 *Cathodic Protection Level 1 Training Manual* (Houston, TX: NACE International, 2000).

2 *Cathodic Protection Level 2 Training Manual* (Houston, TX: NACE, 2000).

3 NACE Standard SP0177-2007, "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems" (Houston, TX: NACE, 2000).

4 F. Brichau, J. Deconinck, "A Numerical Model for Cathodic Protection of Buried Pipes," *Corrosion* 1, 50 (1994): pp. 39-49.

5 F. Brichau, J. Deconinck, T. Driesens, "Modeling of Underground Cathodic Protection Stray Currents," *Corrosion* 6, 52 (1996): pp. 480-488.

6 L. Bortels, "The Use of Dedicated Simulation Software for the Design and Understanding of the Cathodic Protection of Underground Pipeline Networks Under Various Interference Conditions," CORROSION 2003, paper no. 03202 (Houston, TX: NACE, 2003).

7 L. Bortels, J. Deconinck, C. Munteanu, V. Topa, "A General Applicable Model for AC Predictive and Mitigation Techniques for Pipeline Networks Influenced by HV Power Lines," *IEEE Transactions on Power Delivery* 21, 1 (2006): pp. 210-217.

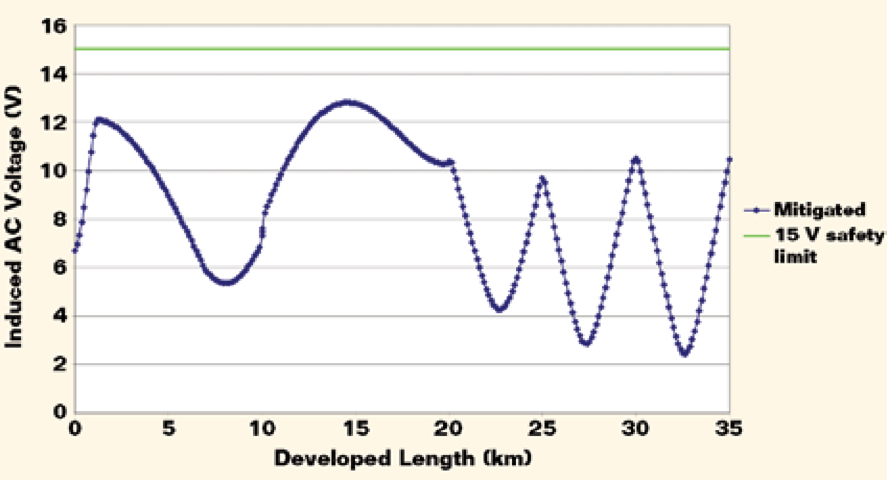
8 L. Bortels, C. Munteanu, V. Topa, J. Deconinck, "A User-Friendly Simulation Software for AC Predictive and Mitigation Techniques," CORROSION 2003, paper no. 03705 (Houston, TX: NACE, 2003).

TABLE 5

Mitigation table

Pipeline (KP)	Grounding Resistance (Ω)	Description
0.00	0.5	Station—pipeline isolated
1.00	1.0	Enter HVAC 1A/1B ROW
7.00	1.0	—
20.00	0.4	90 bend—exits HVAC 1A ROW
25.00	0.5	—
29.78	0.8	Valve station. Enter HVAC 2A ROW
35.00	0.8	Station—pipeline isolated

FIGURE 6



Modeled mitigated induced AC voltages.

This article is based on CORROSION 2010 paper no. 10114, presented in San Antonio, Texas.

LESLIE BORTELS is engineering manager, cathodic protection, at Elsyca NV, Vaartdijk 3/603, Wijgmaal 3018, Belgium, e-mail: leslie.bortels@elsyca.com. He has 15 years of experience in electrochemical modeling and corrosion engineering, including CP, modeling and mitigation of AC-induced voltages, and DC traction interference. He has a Ph.D. in electrical engineering form the University of Brussels, is NACE-certified to CP Level 2, and has been a NACE member for 13 years.

JACQUES PARLONGUE is manager, cathodic protection, at Elsyca NV, e-mail: jacques.parlongue@elsyca.com. He has had 10 years of business responsibilities within high-tech companies in Europe and the United States. A member of NACE, he has an M.S. degree in mining engineering from the University of Brussels.

WOLFGANG FIELTSCHE is manager of Correng Consulting Service, Inc., a subsidiary of Corrosion Service Co., Ltd., 205 Riviera Dr., Markham, ON L3R 5J8, Canada, e-mail: wfieltch@correng.com. He has 14 years of experience in corrosion engineering, including cathodic protection (CP), modeling, and mitigation of AC-induced voltages and AC-enhanced corrosion. A 13-year member of NACE, he has a degree in systems design engineering from the University of Waterloo, Canada; is a NACE-certified CP Specialist; and is a professional engineer.

SORIN M. SEGALL is the technical director at Corrosion Service Co., Ltd., e-mail: ssegall@corrosionservice.com. He has more than 30 years of experience in corrosion engineering, including CP, mitigation of AC-induced voltages, and direct assessment of external corrosion. He has an M.S. degree in electrical engineering from the University of Bucharest, Romania; is a NACE-certified CP Specialist; and is a professional engineer. He is an 18-year member of NACE. MP