Commission 2

Menthon-Saint-Bernard DAYS – 24st –26th May, 2011

Paper 2 - 15

AC STRAY CURRENT DUE TO OHMIC INTERFERENCE

Claes Taxen, Bertil Sandberg, SwereaKIMAB, Box 55970, 102 16 Stockholm, Sweden

Abstract

When planning new pipelines, careful calculations are being performed concerning inductive interference due to parallel routing with three-phase, high-voltage overhead power lines. The ohmic interference due to the vicinity of overhead power line pylons is less considered. Often a minimum distance of just a few meters is requested.

In most areas in Sweden, the bed rock is only covered by a thin layer of soil, which to 70% consists of moraine. These poor conditions for grounding result in many cases in extensive gradient fields around pylons giving long term interference on adjacent pipelines. These problems have been identified first when the pipeline is installed. Before installing new pipelines this ohmic interference will be taken into account by a combination of field measurements and interference calculations.

Zusammenfassung

Bei der Planung neuer Pipelines werden sorgfältige Berechnungen zur induktiven Beeinflussung durch parallele Trassenführung von dreiphasigen Hochspannungshochleitungen durchgeführt. Die ohmsche Beeinflussung aufgrund der Nähe von Hochspannungsmasten wird seltener berücksichtigt. Oftmals wird nur ein Mindestabstand von wenigen Metern gefordert.

In den meisten Gebieten Schwedens ist das Grundgestein nur von einer dünnen Bodenschicht bedeckt, die zu 70 % aus Moränen besteht. Diese Fließbedingungen für die Erdung führen in vielen Fällen zu intensiven Gradientenfeldern rund um Masten, die benachbarte Pipelines langfristig beeinflussen. Diese Probleme wurden erstmals festgestellt, als die Pipeline verlegt wurde. Vor dem Verlegen neuer Pipelines wird diese ohmsche Beeinflussung durch eine Kombination von Feldmessungen und Interferenzberechnungen berücksichtigt.

Résumée

Lors de la planification de nouvelles canalisations, des calculs minutieux sont réalisés à propos des interférences par induction dues à l'acheminement parallèle à des lignes aériennes de courant triphasé à haute tension. Les interférences galvaniques dues à la proximité des pylônes électriques sont moins prises en considération. Souvent, une distance minimale d'à peine quelques mètres est requise.

Dans la plupart des régions de Suède, le substrat rocheux n'est couvert que d'une fine couche de sol, qui consiste pour 70 % en de la moraine. Ces mauvaises conditions de mise à la terre résultent dans bien des cas en des champs de gradient étendus autour des pylônes, ce qui produit des interférences à long terme sur les canalisations adjacentes. Ces problèmes ont d'abord été identifiés quand la canalisation est installée. Avant d'installer de nouvelles canalisations, ces interférences galvaniques seront prises en compte par une combinaison de mesures sur place et de calcul des interférences.

Introduction

When planning new pipelines, careful calculations are being performed concerning inductive interference due to parallel routing with three-phase, high-voltage overhead power lines. The ohmic interference due to the vicinity of overhead power line pylons is less considered. Often a minimum distance of just a few meters is requested.

In most areas in Sweden, the bed rock is only covered by a thin layer of soil, which to 70% consists of moraine. These poor conditions for grounding result in many cases in extensive gradient fields around pylons giving long term interference on adjacent pipelines. These problems have been identified first when the pipeline is installed. Before installing new pipelines this ohmic interference will be taken in to account by a combination of field measurements and interference calculations. In this paper, the model used for the interference calculations, is presented.

In connection with the planning of a new pipeline existing electric fields along the planed route are measured in the field. The soil resistivity is also determined at selected places. This information together with technical data for the steel pipe and the coating are then used in the model to calculate expected voltages on the pipeline and to evaluate possible mitigations if the voltage is too high.

Equivalent circuit for a buried pipeline

The equivalent circuit for a buried pipeline is presented in figure 1.

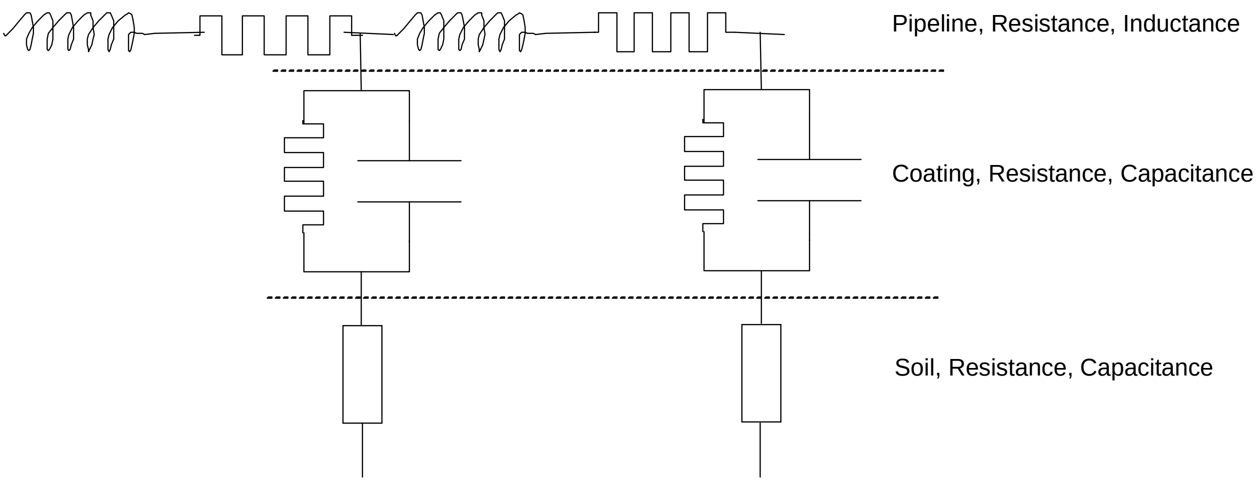

Figure 1. Equivalent circuit for a buried pipe.

For pipelines with high specific coating resistance the impedance of the soil can be neglected

In the model we regard the pipeline as many serial impedances, Z_L, in parallel with impedances pipeline to earth, Z_T, see figure 2.

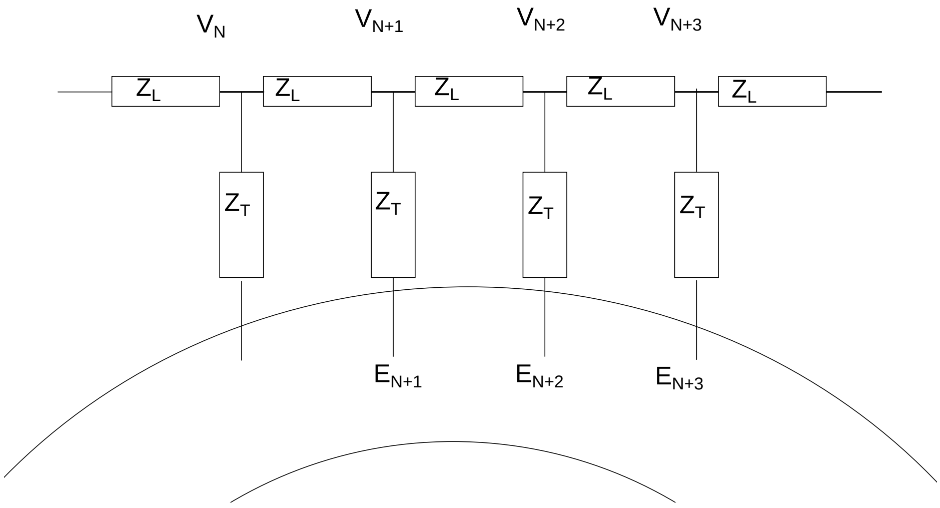

Figure 2. Model for a pipeline exposed to ground potentials.

V_N = Pipe potential in point N (V).
Z_L = Serial impedance of pipe (Ω/m).
Z_T = Pipe to soil impedance (Ωm).
E_N = Ground potential in point N (V).

The serial impedance has a resistive and an inductive part and can be calculated using the following formula (1):

$$Z_L = \frac{\sqrt{\rho_\rho \cdot \mu_0 \cdot \mu_r \cdot \omega}}{\pi \cdot D \cdot \sqrt{2}} + \frac{\mu_0 \cdot \omega}{8} + j \cdot \left(\frac{\sqrt{\rho_\rho \cdot \mu_0 \cdot \mu_r \cdot \omega}}{\pi \cdot D \cdot \sqrt{2}} + \frac{\mu_0 \cdot \omega}{2 \cdot \pi} \cdot \ln\left(\frac{3.7 \cdot \sqrt{\rho \cdot \omega^{-1} \cdot \mu_0^{-1}}}{D} \right) \right) \quad (1)$$

ρ_ρ = resistivity of the pipeline steel (Ωm)
μ_0 = magnetic permeability of the air (H/m)
μ_p = relative permeability of the pipeline steel
ω = angular frequency (s^{-1}) = 2π50 at 50 Hz
D = diameter of pipeline (m)

The impedance between pipe and soil is the inverted value of the admittance, y. The total admittance y_T depends on the admittance between pipeline and soil y_c, and the admittance due to the surrounding soil y_e. The magnitude of y_c is controlled by the coating.

$$y_T = \frac{y_c \cdot y_e}{y_c + y_e} \quad (2)$$

$$y_c = \frac{\pi \cdot D}{\rho_c \cdot \delta_c} + j \cdot \omega \cdot \frac{\varepsilon_0 \cdot \varepsilon_{r,c} \cdot \pi \cdot D}{\delta_c} \ (\Omega^{-1}\mathrm{m}^{-1}) \quad (2a)$$

$$y_e = \frac{\pi \cdot (1/\rho + j \cdot \omega \cdot \varepsilon_{r,soil})}{\ln(1.12/\gamma a')} \ (\Omega^{-1}\mathrm{m}^{-1}) \quad (2b)$$

ρ_c = coating resistivity (Ωm)
ε_0 = electrical permittivity of the air (F/m)
$\varepsilon_{r,c}$ = relative permittivity of the pipeline coating
$\varepsilon_{r,soil}$ = electrical permittivity of the soil
δ_c = thickness of the coating (m)
ρ = soil resistivity (Ωm)
γ = propagation constant of the circuit pipeline/earth = $\sqrt{Z_L \cdot y_T}$ (m^{-1})

$a' = \sqrt{a^2 + 4h'^2_p}$ where *a* is pipe radius (m) and h'_p is the depth of buried pipe (m)

Generally for coated pipelines $y_e >> y_c$ therefore $y_T \sim y_c$.

The coating resistivity depends on the extent of defects and pores. The most reliable value is achieved using the current demand for the cathodic protection. The resistive part of formula 2a should therefore be replaced with the factor: $\frac{\pi \cdot D \cdot i}{U}$ (3)

i = current demand ($\mathrm{A/m^2}$)

U = difference between On- and Off-potential (V)

Giving:

$$y_c = \frac{\pi \cdot D \cdot i}{U} + j \cdot \omega \cdot \frac{\varepsilon_0 \cdot \varepsilon_{r,c} \cdot \pi \cdot D}{\delta_c} \quad (4)$$

The pipeline characteristic impedance, Z_c, can be expressed as the geometric mean of the serial impedance and the pipe to soil impedance. We get the following formula:

$$Z_C = \sqrt{\frac{Z_L}{y_T}} \quad (5)$$

Other pipeline parameters are the propagation constant γ and the characteristic length of the pipeline, see below.

$$\gamma = \sqrt{Z_L \cdot y_T} \quad (6)$$

$$\lambda = \frac{1}{\mathrm{Re}(\gamma)} \quad (7)$$

where Re(γ) is the real component of γ.

Model for interference calculation

The pipeline is divided into shorter distances adjusted so the ground potential in each point of intersection is available from the field survey.

According to Kirchhoffs law, the sum of current in each point of intersection is zero. This gives the following expression for the pipe potential, V_N, in point N i figure 2.

$$\frac{(V_N - V_{N-1})}{Z_L} + \frac{(V_N - V_{N+1})}{Z_L} + \frac{(V_N - E_N)}{Z_T} = 0 \qquad (8)$$

We substitute the impedances with the complex admittances y_L and y_T according to:

$y_L=1/Z_L$ (9)

$y_T=1/Z_T$ (10)

From equation (6) the following expression for V_N can be obtained:

$$(V_N - V_{N-1}) \cdot y_{Ln} + (V_N - V_{N+1}) \cdot y_{Lu} + (V_N - E_N) \cdot y_T = 0$$

where y_{Ln} = serial impedance to the left from the point of intersection and y_{Lu} = serial impedance to the right.

$$V_N - \frac{y_{Ln}}{y_{Ln} + y_{Lu} + y_T} \cdot V_{N-1} - \frac{y_{Lu}}{y_{Ln} + y_{Lu} + y_T} \cdot V_{N+1} = \frac{y_T}{y_{Ln} + y_{Lu} + y_T} \cdot E_N \qquad (11)$$

For a part of the pipeline the following matrix can be put up:

V_1	V_2	V_3	V_4	V_5	V_5	. . .	
1	$-A_{L,u}$	0	0	0	0		$=A_{L,n}*V_0+A_T*E_1$
$-A_{L,n}$	1	$-A_{L,u}$	0	0	0		$=A_T*E_2$
0	$-A_{L,n}$	1	$-A_{L,u}$	0	0		$=A_T*E_3$
0	0	$-A_{L,n}$	1	$-A_{L,u}$	0		$=A_T*E_4$
0	0	0	$-A_{L,n}$	1	$-A_{L,u}$		$=A_T*E_5$
.							=
.							
.							

where $A_{Ln} = \frac{y_{Ln}}{y_{Ln} + y_{Lu} + y_T}$ $\quad A_{Lu} = \frac{y_{Lu}}{y_{Ln} + y_{Lu} + y_T}$ and $A_T = \frac{y_T}{y_{Ln} + y_{Lu} + y_T}$

To solve the matrix, the ground potentials must be known at each ending points of the regarded pipe section. The ending points are connected to a known potential V_0 through an impedance. This impedance can vary depending on the section being ended with a grounding, an isolating joint or is continuing.

In the following we give an example on the results obtained by the model. A polyethylene coated pipeline with a diameter of 400 mm is buried in a homogenous soil having a resistivity of 500 Ωm. The evaluated section of the pipeline has no groundings or isolating joints.

A local resistive gradient field in accordance with figure 3 was assumed to exist.

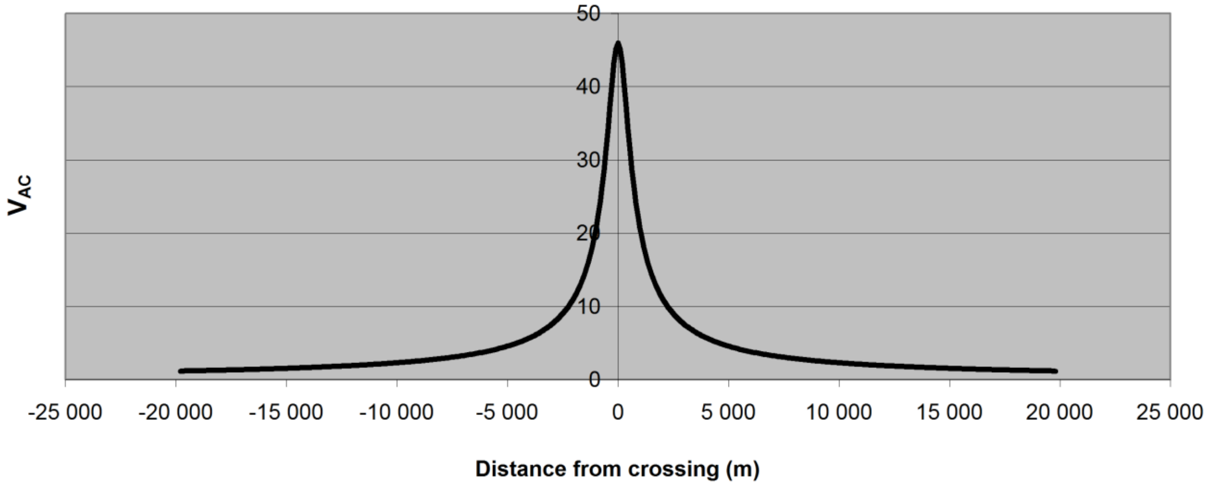

Figure 3. Assumed ground potentials.

Calculated pipe potentials versus remote earth are shown in figure 4, giving the pipe potentials versus local ground presented in figure 5.

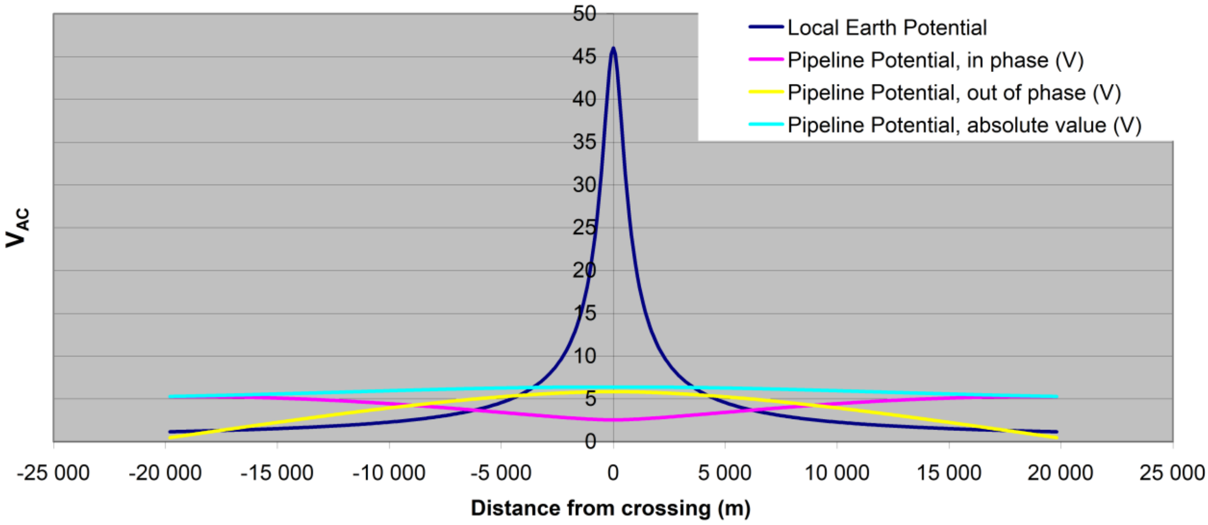

Figure 4. Assumed ground potentials and calculated pipe potentials versus remote earth.

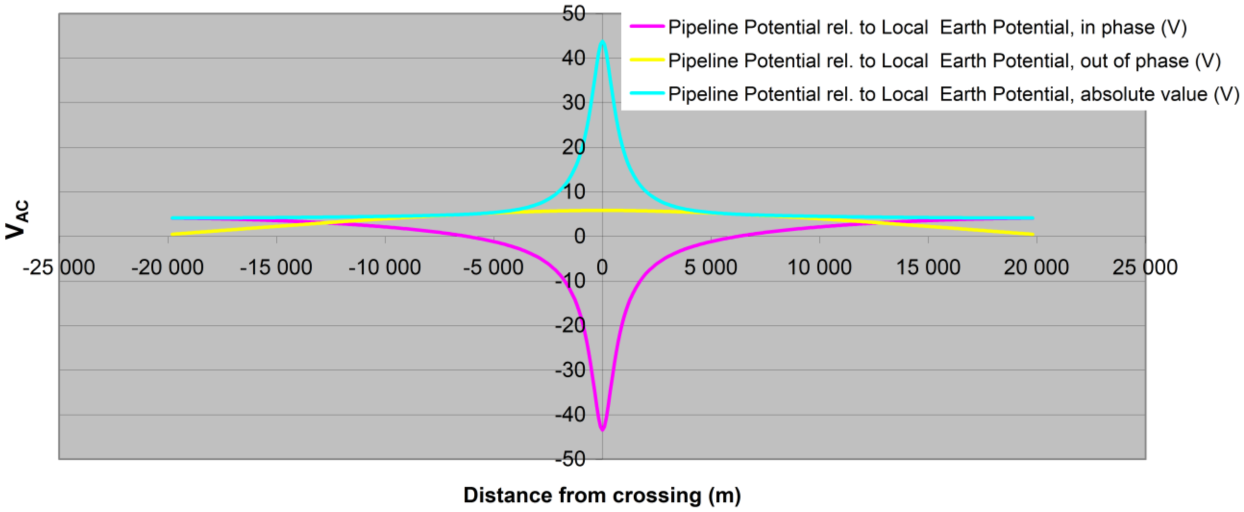

Figure 5. Pipe potentials versus local ground.

The angular phase difference results in a potential difference between pipe and local ground which is somewhat lower than the potential difference between local ground and remote earth. This can be shown in a vector diagram. Figure 6 represents the most exposed point in the crossing.

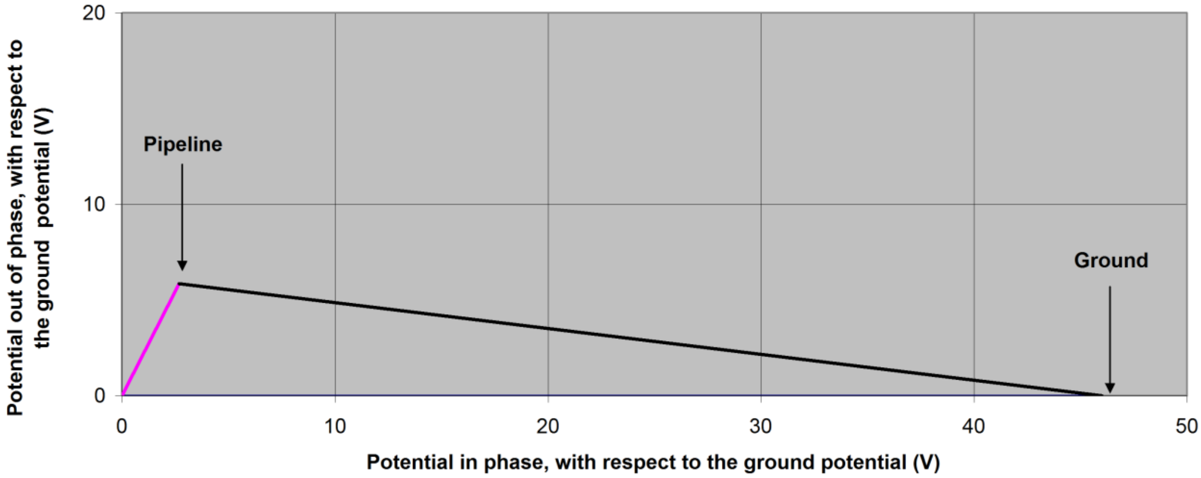

Figure 6. Ground potential and pipe potential versus remote earth in the most exposed point presented in a vector diagram.

An interesting observation is that most of the current being transferred to the pipeline is done so in capacitive way. Only a small proportion is transferred as resistive current, se figure 7.

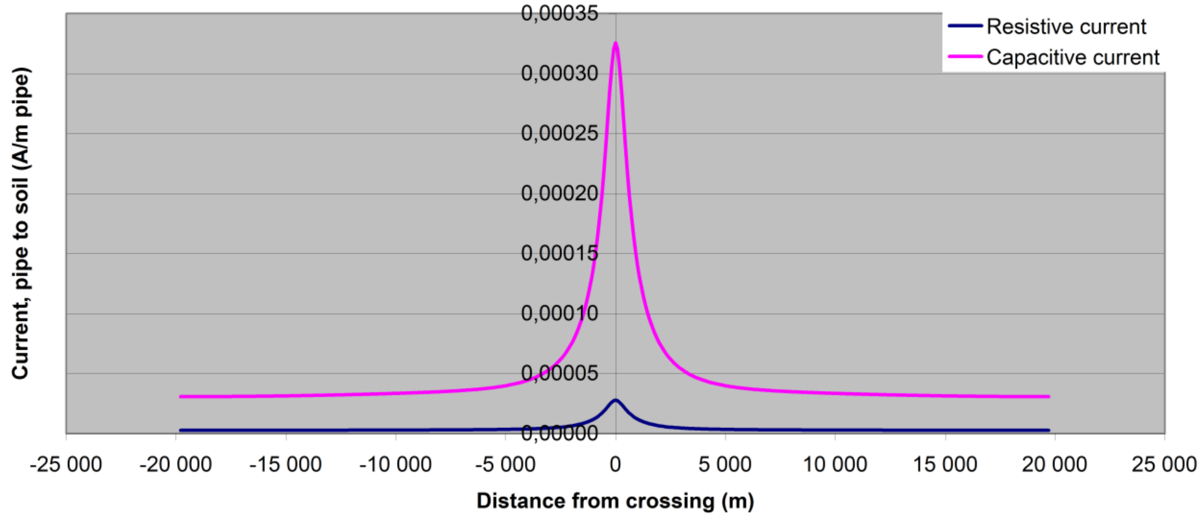

Figure 7. Current transfered between pipe and ground per metre pipe.

The current flow in the pipeline varies in accordance with figure 8.

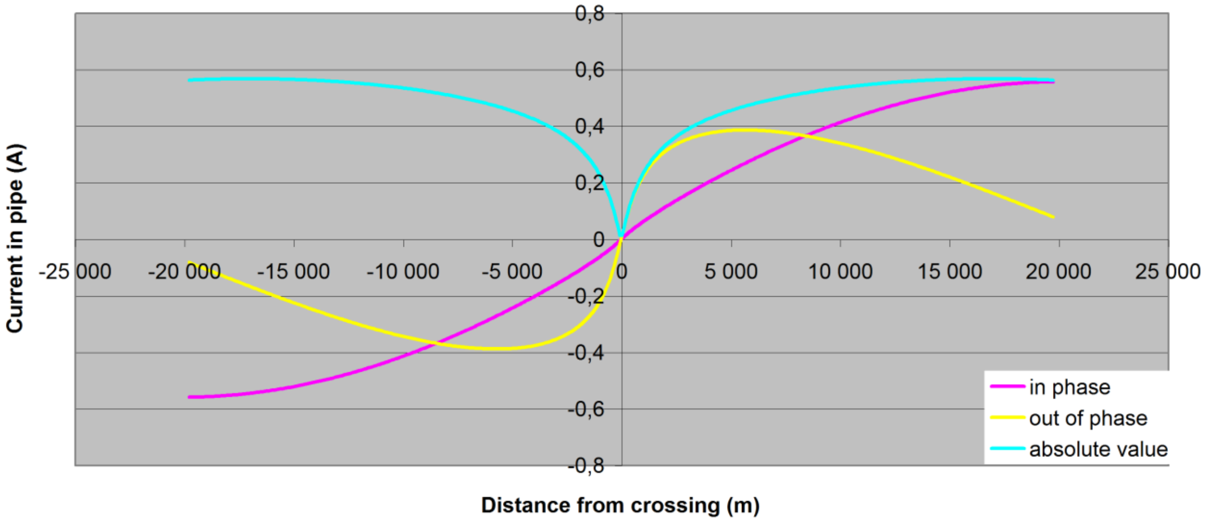

Figure 8. Current flow in pipe.

The calculations also showed that also large coating damages will have only small influence on the voltage of the pipe. It is therefore possible to calculate the ac current density in damages if the soil resistivity is known. The resistance is approximated as the sum of the resistance in the defect and the resistance in the surrounding soil.

$$R_{coating} = \frac{\rho \cdot \delta \cdot 4}{\pi \cdot d^2} \qquad (12)$$

$$R_E = \frac{\rho}{2 \cdot d} \qquad (13)$$

d = diameter of defect [m], δ= coating thickness [m], ρ= soil resistivity [Ωm]

Verification of the model

The model has been verified by comparing the results with field measurements from the interfered pipeline Getinge-Mosshult (presented by Edwall, Malmborn CEOCOR 2011). The pipeline has a diameter of 405 mm and a 2,2 mm thick polyethylene coating. The current demand is 0,15 μA/m^2. The pipeline is interfered by a resistive gradient field caused by stray current from a crossing power line in the middle of the pipe length.

In figure 9 results from field measurement, ground potentials and pipe voltages, are presented.

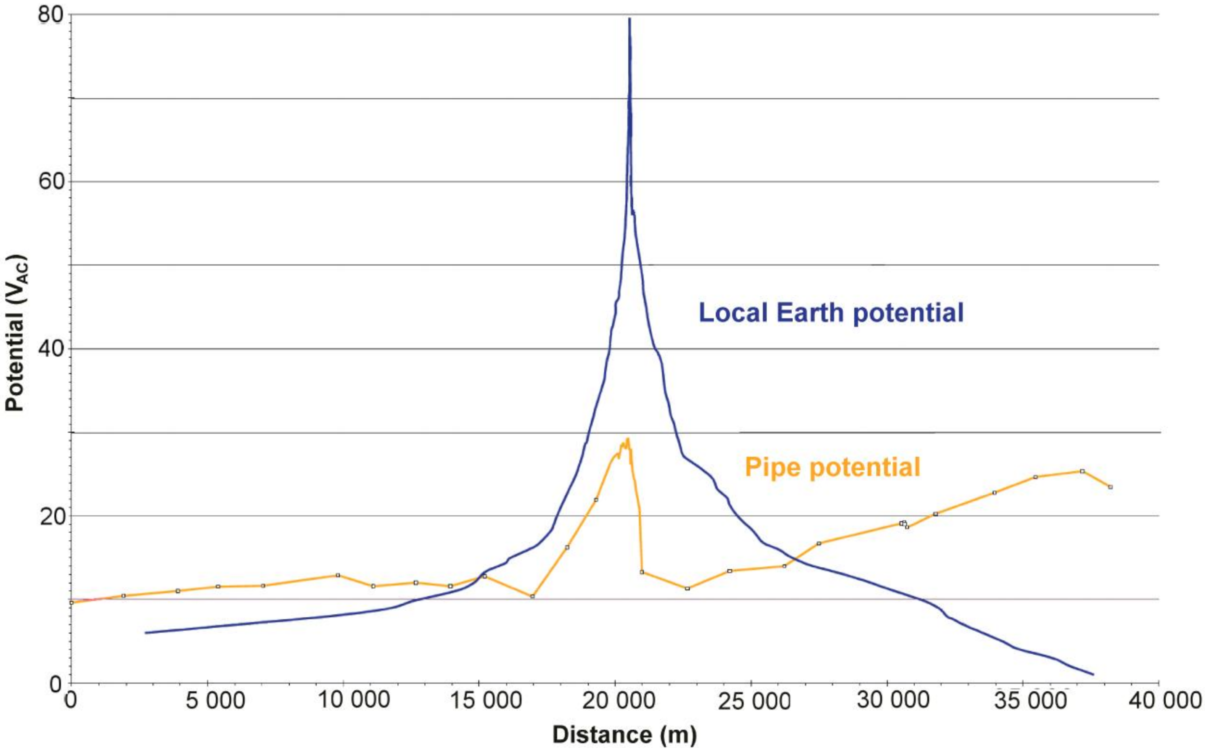

Figure 9. Ground potentials and pipe voltages measured in the field.

The soil resistivity was measured in a number of places giving the interpolated curve seen in figure 10.

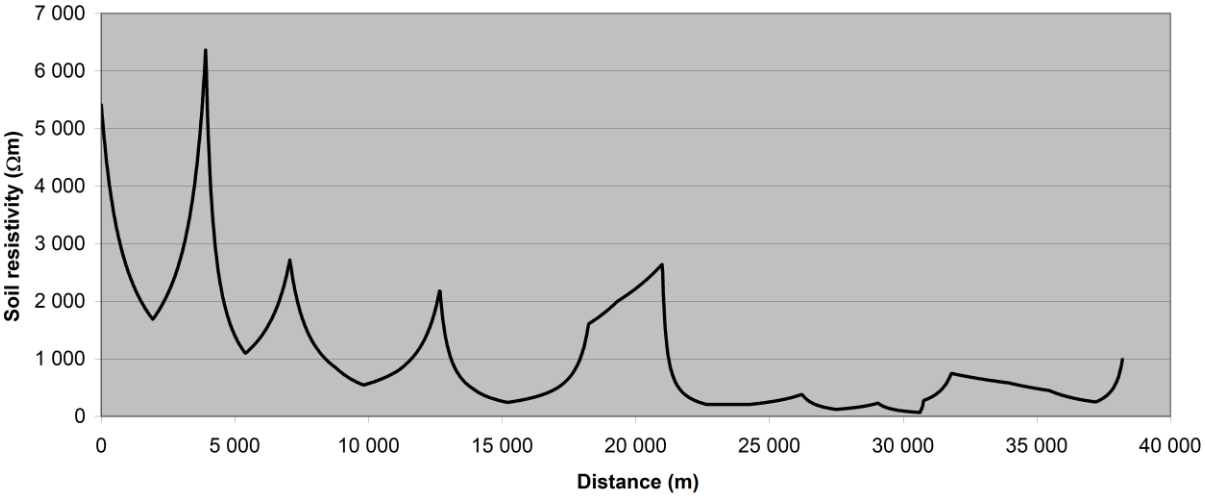

Figure 10. Soil resistivity data used in the calculation.

Based on these data the pipe to soil potential was calculated giving the results in figure 11. The results from the field measurements are presented in the same diagram. The main reason for the differences is believed to be not enough accurate data of soil resistivity.

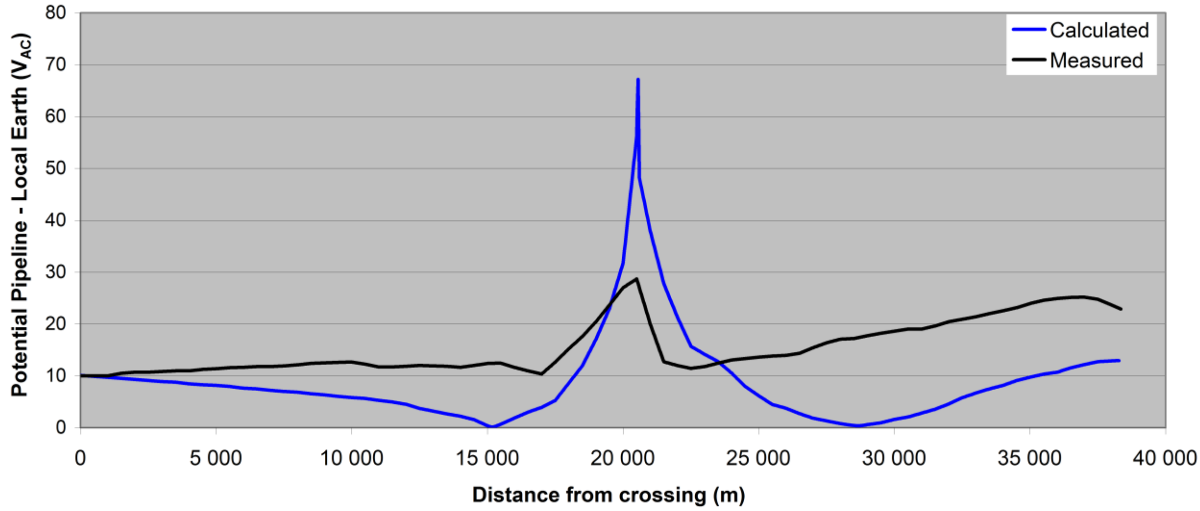

Figure 11. Calculated and measured pipe potentials.

To reduce the level of interference, 8 isolating joints were installed, 4 on each side of the crossing, lowering the potentials in accordance with figure 12.

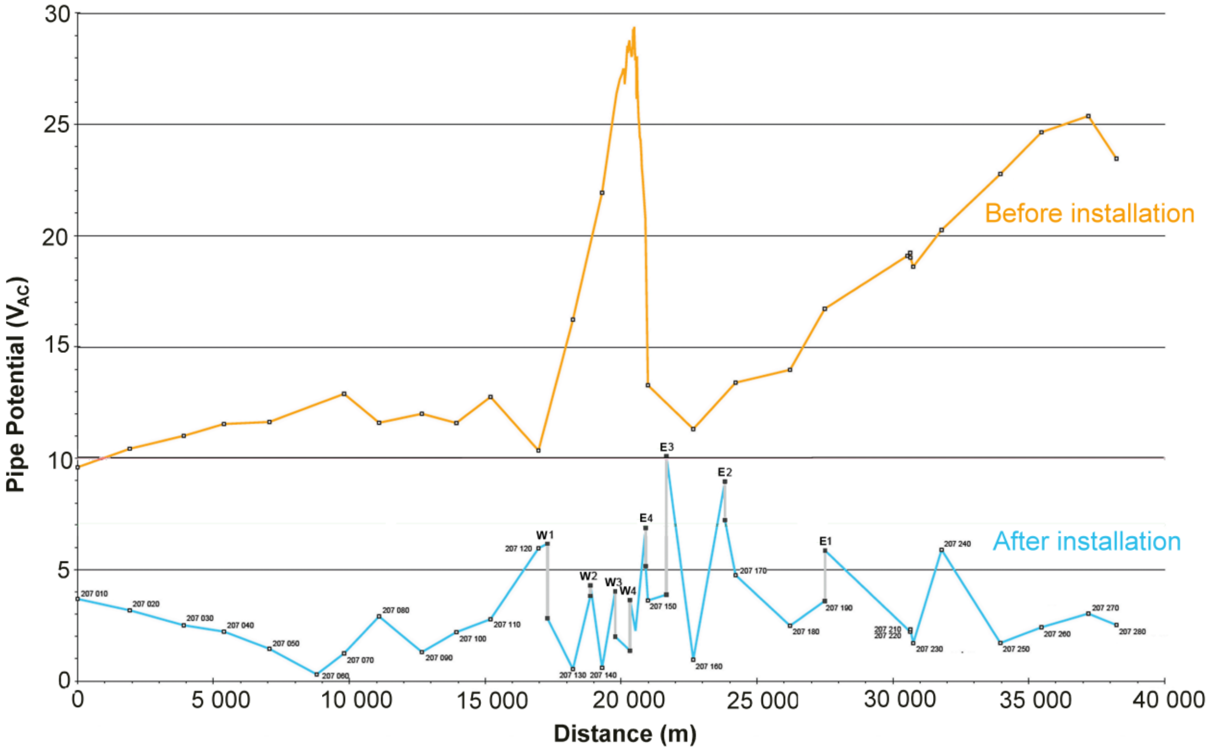

Figure 12. Pipe potentials before and after installation of 8 isolating joints.

The potential levels close to the crossing is shown in figure 13.

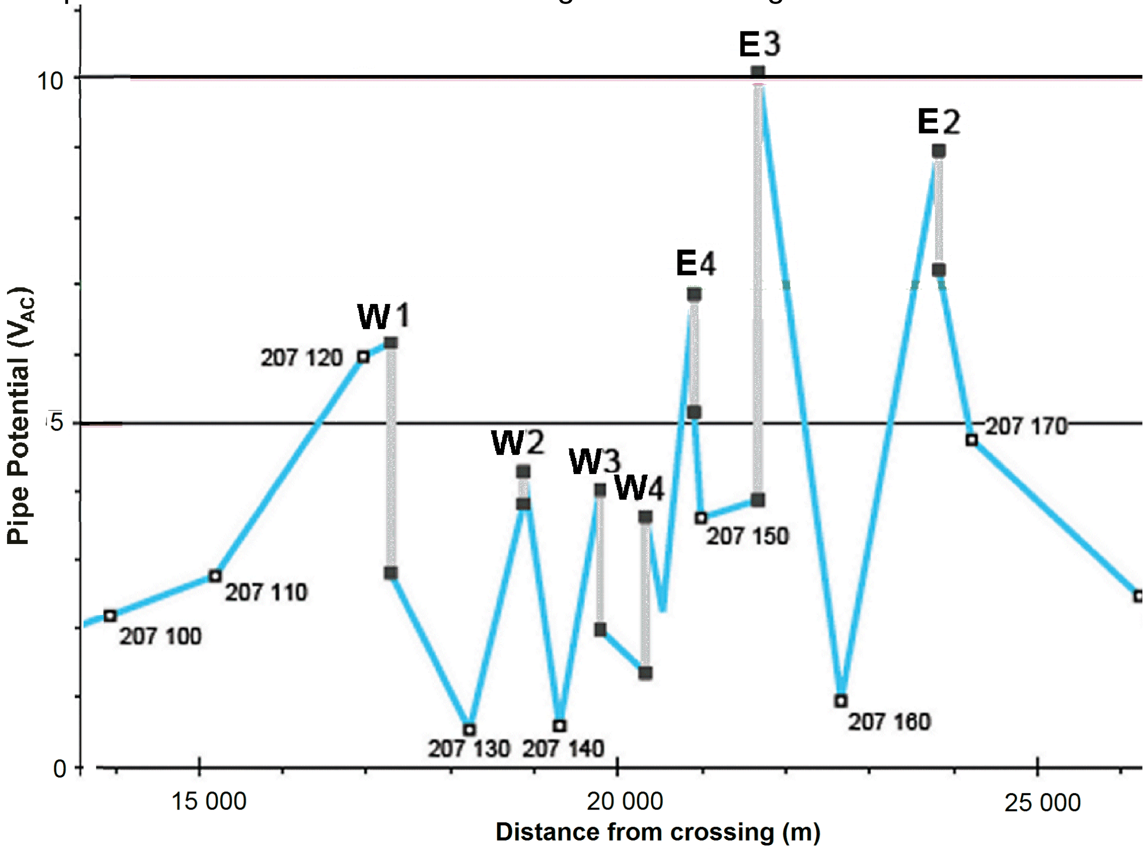

Figure 13. Pipe potentials in the vicinity of the crossing.

The corresponding values calculated in the model can be seen in figure 14.

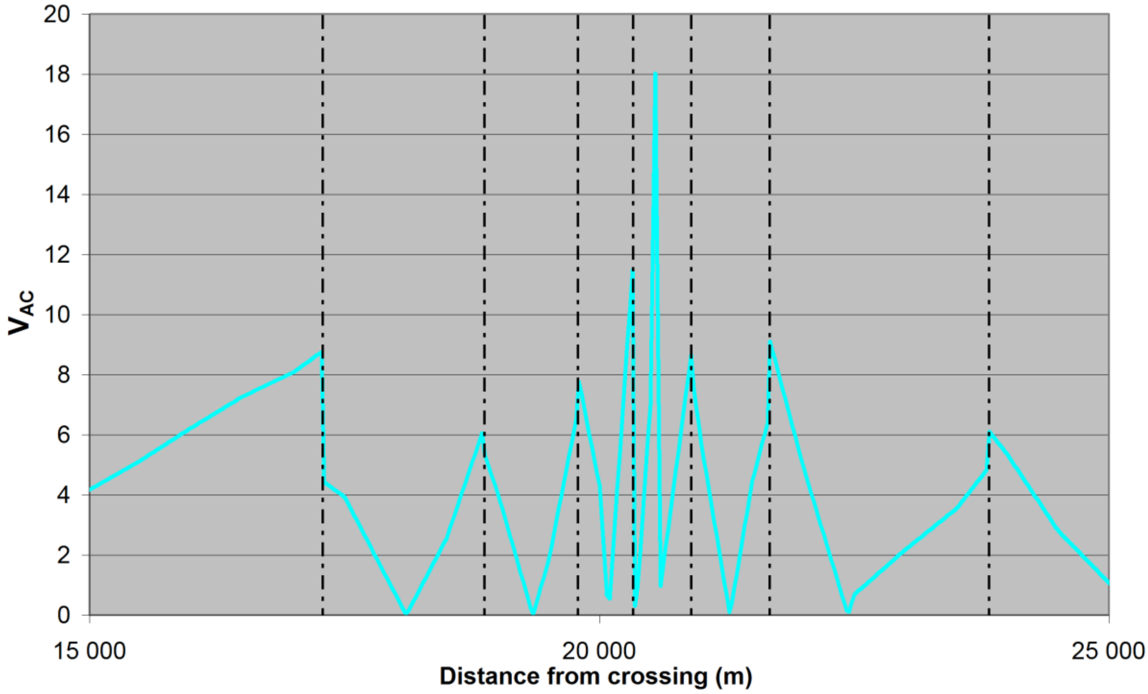

Figure 14. Calculated pipe potentials in the vicinity of the crossing.

The model indicates a high voltage peak between the two isolating joints W4 and E4. This has however not been verified in field measurements. The pipe potentials in the vicinity of the isolating joints are of the same magnitude in the model (6-11,5 V) as in the field measurements (3,6-10,1 V).

Summar

The performed investigation permits the following conclusions (valid for well coated pipelines):

- Minor coating damages do not affect the potential of the pipeline.
- The capacitive current transferred to the pipe is much larger than the resistive current.
- The model gave higher potentials on the pipeline than field measurements. The reason is attributed to poor accuracy and resolution in the input data, primarily soil resistivity.
- In spite of imperfect input data, acceptable results were obtained from simulations of the remedies.

References

1. CIGRE (2006): AC Corrosion on metallic Pipelines due to Interference from AC Power Lines. CIGRE Joint Working Group C4.2.02. April 2006.

2. Electrical interference on cathodically protected pipelines. December 2010. Swedish report.