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Investigation of Electromagnetic Interferences Issues

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***Abstract*- Electromagnetic interferences between an existing high voltage power line and a gas stream network sharing the same right-of-way are evaluated. Induced voltages are determined for different steady state power line operating conditions, using professional software. To increase results accuracy, soil resistivity measurements were made along the distribution corridor and the appropriate equivalent soil model is identified. Obtained induced AC voltages values are compared to international regulation for potentially hazardous zones identification regarding pipeline corrosion.**

***Keywords*: electromagnetic interferences, induced voltages, pipelines, power lines**

I. INTRODUCTION

Due to ecological regulations and economic policies, the situations where a buried gas pipeline and one or more high voltage power line (HVPL) share proximal rights-of-way for considerable lengths are a common situation in practice. A pipeline which shares a common corridor with AC transmission lines becomes energized by the magnetic and electric fields surrounding the power system in the air and soil. This AC interference can result in an electrical shock hazard for people touching the pipeline or simply standing nearby; furthermore, damage to the pipeline's coating, insulating flanges, rectifiers or even direct damage to the pipeline's wall itself can occur [1 - 6].

To provide proper protection for the operating personal, European Standard Regulations [7, 8], limit the induced AC voltage level in metallic pipelines according to HVPL working conditions and soil resistivity.

Table I presents the limits for the induced AC voltages for different HVPL fault conditions [7].

TABLE I
TYPE SIZES FOR CAMERA-READY PAPERS

Fault duration t[s]	Induced voltage (RMS value)[V]
t ≤ 0.1	2000
0.1 < t ≤ 0.2	1500
0.2 < t ≤ 0.35	1000
0.35 < t ≤ 0.5	650
0.5 < t ≤ 1.0	430
1 < t ≤ 3	150
t > 3	60

In order to respect these regulations a detailed study of the electromagnetic interference between HVPL and MP has to be done focused on induced AC voltage levels. These induced voltages can be caused by any of the following three types of couplings [9 -15]:

Inductive Coupling: Time varying magnetic fields generated by AC transmission line currents in EPL induce currents flowing in conducting pipeline and voltages between it and surrounding soil.

Capacitive Coupling: Affects only aerial pipelines situated in the proximity of HVPL. It occurs due to the capacitance between the line and the pipeline. For underground pipelines the effect of capacitive coupling may not to be considered, because of the screening effect of earth against electric fields.

Conductive Coupling: When a ground fault occurs in HVPL the current flowing through the grounding grid produce a potential rise on both the grounding grid and the neighboring soil with regard to remote earth. If the pipeline goes through the "zone of influence" of this potential rise, then a high difference in the electrical potential can appear across the coating of the pipeline metal.

The objective of this study is to obtain the values of induced voltages in underground gas pipelines, by a high voltage transmission line, using a professional analysis and modeling software.

II. STUDIED INTERFERENCE PROBLEM

An existing 400kV/50Hz single circuit electrical power line from the Romanian Transmission System shares a common distribution corridor with a major gas stream network named Isaccea-Negru Vodă.

The HVPL phase wires are placed on horizontal structure electrical towers at 35m above ground and 2 sky wires placed at 41m above ground.

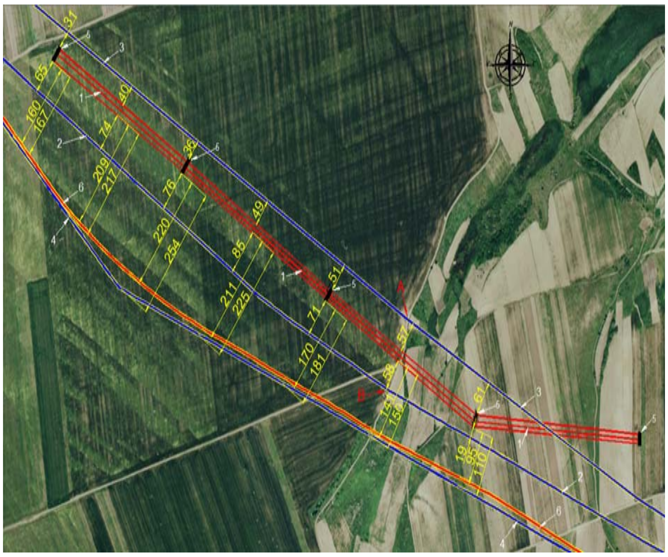
The gas stream network consists of 4 parallel underground metallic pipelines (Fig. 1):

1) Transit Pipeline (MP_T1) – is functionally from 1974; it has a 1000mm outer diameter, bitumen insulation and a wall thicknesses of 11,5mm, 12,44mm and 13,5mm.

2) Import Pipeline (MP_I) Isaccea–Mihai Bravu – is functionally from 1978, it has a 600mm outer diameter; bitumen insulation and a wall thickness of 6mm.

3) Transit Pipeline (MP_T2) - is functionally from 1988, it has a 1200mm outer diameter; strengthened bitumen insulation and a wall thicknesses of 14,3mm and 17,3mm.

4) Transit Pipeline (MP_T3) - is functionally from 2003, it has a 1200mm diameter; strengthened bitumen insulation and a wall thicknesses of 14mm, 17mm and 22mm.



1 – HVPL 400kV/50Hz; ***2 – Transit Pipeline MP-T1;***
3 – Transit Pipeline MP-T3; ***4 – Transit Pipeline MP-T1;***
5 – HVPL Electric Tower; ***6 – Import Pipeline (MP-I)***

Fig. 1. Plan view of the HVPL-MPs common distribution corridor.

All considered pipelines have an electrical conductivity equal to σ = 5,882 MS/m and a relative magnetic permeability equal to $\mu_r = 300$ respectively.

Values of induced AC voltages in the considered gas metallic stream pipelines network, due to nearby HVPL, were computed using the HIFREQ and RESAP modules of the CDEGS professional analysis and modeling software package. [10]

Obtained result are compared with practical onsite measurements, made at points A and B, located along pipelines MP_T3 and MP T2 (see Fig. 1).

III. Soil Resistivity Analysis

The current flowing from remote earth to a pipeline runs through the soil, hence the ohmic resistance provided by that soil is an important parameter in studying the AC induced voltage corrosion.

The ohmic resistance provided by the soil is controlled by factors relating to the resistance of the soil solution itself, the porosity of the soil, and geometrical factors existing close to the interface between the soil and the segment of pipeline under consideration. The resistance of the soil (Rs) solution itself is inversely related to the conductivity of the solution and determines the amount of AC-voltage being lost across the soil resistance (magnitude of the IR drop related to the AC voltage). This means that if Rs is very high, a high degree of the AC voltage is lost across the soil resistance thus degreasing the amount of AC voltage reaching the pipe, and vice versa. Therefore, the soil resistivity determination is a very important aspect in a detailed survey on a pipeline and consists in a valuable aid when interpreting the severity of corrosive areas [16-18].

The use of equivalent horizontally layered soil models are the more practical approach (and quite more realistic) for the cases where the conductivity of the ground is not uniform with depth. This approach consists in considering the earth as being stratified in a certain number of layers of different resistivity and thickness. The apparent scalar resistivity is obtained starting from experimental measurements or according to approximate composition of each earth layer.

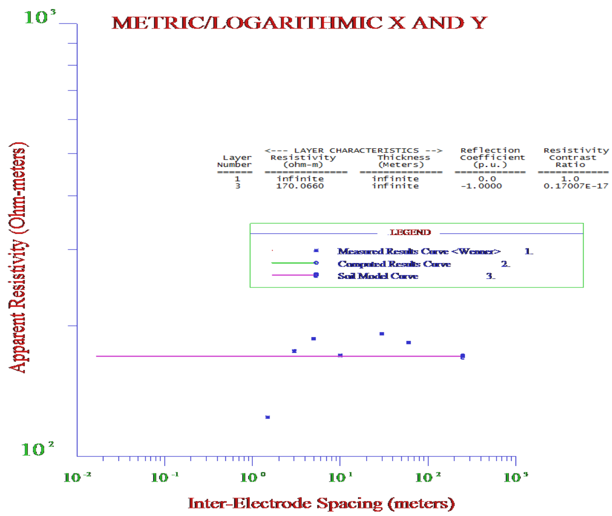


Fig. 2. Computed uniform soil model.

To determine the appropriate equivalent horizontally layered soil model for the studied HVPL-MPs interference problem, the RESAP module from CDEGS software package was used according with soil resistivity measurement at site. An investigation of the measurement data showed that it is appropriate to use a de 170 Ω·m uniform soil model because it conserves all the important features of the real soil characteristics (Fig. 2).

IV. Evaluation of Induced Currents and Voltages

A. Steady-State Operating Conditions

Initially, the induced AC currents and voltages are evaluated in the underground MP during power line steady-state conditions with a 700A symmetrical current load.

If AC voltages are induced in a metallic pipeline, induced AC currents will pass through the metal surface to insulation defects. The values of these currents depend on the values of the total voltage of the electric system. Therefore, the induced currents increase with the induced voltages.

A detailed analysis regarding the repartition of induced currents and voltages along pipeline length is suggestively presented in Fig. 3.

Accordingly to this representation, the pipeline segments were the induced voltages records the highest values are located at the ends of the HVPL – MPs common distribution corridor.

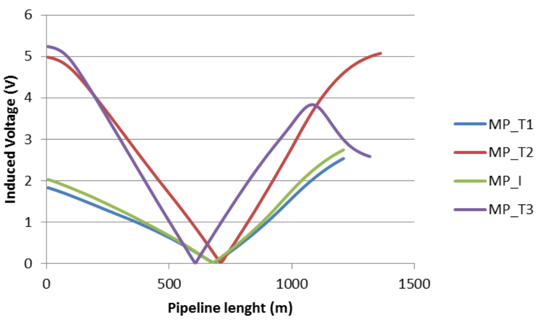


Fig. 3. Induced voltages along underground MPs.

In case of MP T3, peak values of the induced voltage are obtained in the right area where MPs under cross HVPL due to different orientation of the electromagnetic field on electric power line both sides. Also there are recorded a much lower induced voltage values in MP_T1 and MP_I, due to much larger separation distance between these two technological metallic structures and the HVPL. [9-11]

Based on RMS and phase value of AC induced voltages at the ends of the pipelines sections, provided by the CDEGS software, the time variation of MP_T3 and MP_T2 potentials, at points A and B, was determined. This computed values were compared with induced voltage values measured using coupons installed near pipelines, considered to have a 0,6V potential, regarding the Cu/CuSO4 reference electrode.

In case of the pipeline MP_T3 and for a 700A HVPL current load, was recorded (right to point A) a measured induced potential by 2,812V for RMS value and -100,89° for the phase (Fig. 4).

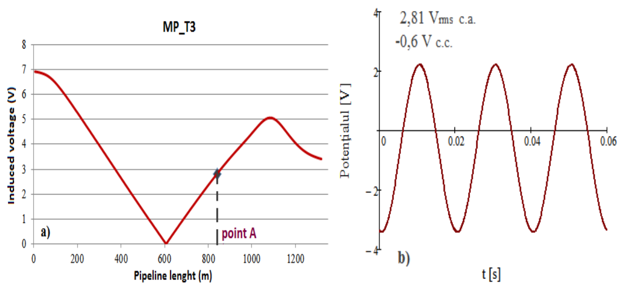


Fig. 4. a) Value of the AC induced voltages along MP_T3; b) Time variation of the MP_T3 potential in point A regarding the $CuCuSO_4$ electrode.

Likewise, the pipeline MP_T2 recorded AC induces voltages (right to point B) with 0,571V RMS value and 73,54° phase value (Fig. 5).

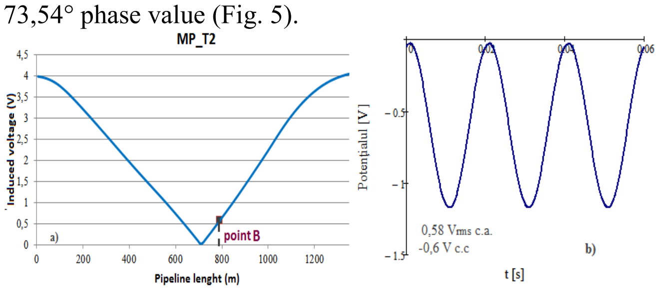


Fig. 5. a) Value of the AC induced voltages along MP_T2; b) Time variation of the MP_T2 potential in point B regarding the *$CuCuSO_4$* electrode.

Romanian statistics mentioned that, power flow through a 400kV power line varies between 140-180MVA. Therefore, to investigate the induced AC potential levels that can occur for different power flows, in case of those studied MPs, the symmetrical current load on HVPL was considered in the range of 600-800A. Accordingly to Fig. 6, the level of the induced voltage in metallic pipelines increases linearly with the value of current load.

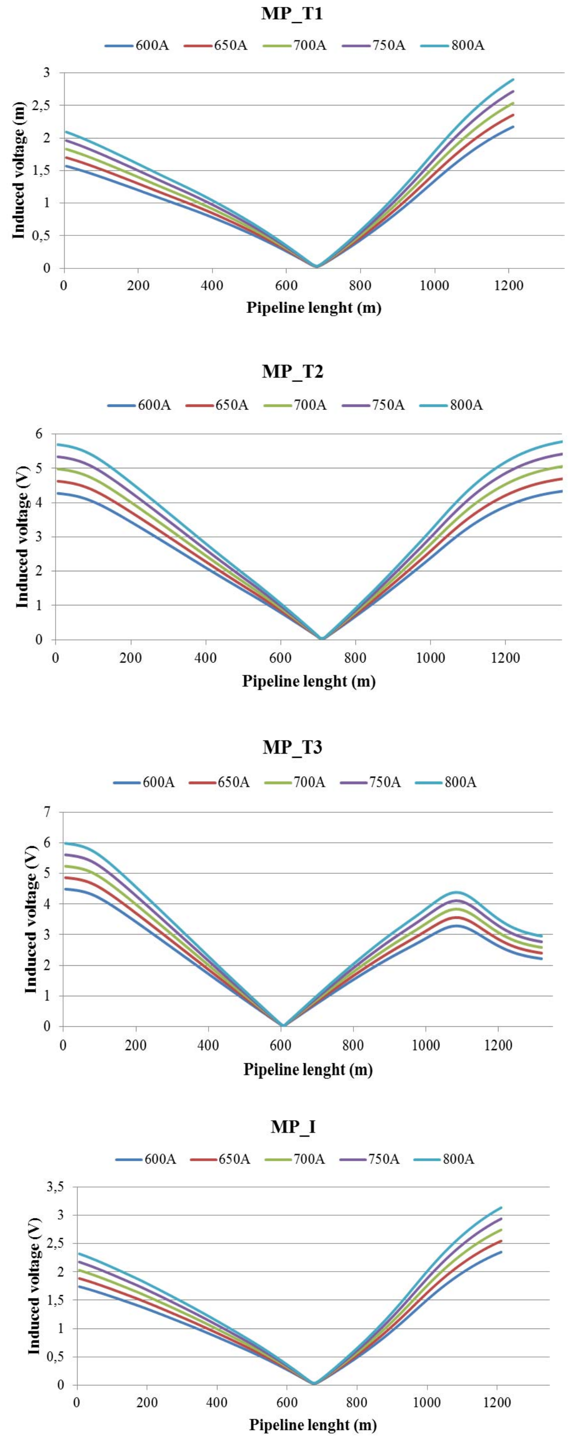


Fig. 6. Induced Voltages along MP's in case of different current load for pipelines MP_T1; P_T2; MP_T3 respectively MP_I

Therefore, an increase of 33% of the current load produce a 25% increase of the AC induced potential. Fig. 6 reveals the variation of the RMS values in case of induced voltages along pipelines MP_T2 and MP_T3, right to measuring points A and B.

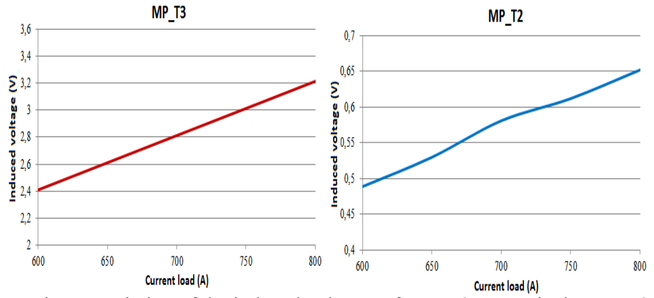


Fig. 7. Variation of the induced voltages of MP_T3 respectively MP_T2 right to points A and B, in case of different current load

B. Unbalanced Load Operating Conditions

In practice, usually unbalanced current loads are present, the symmetrical current load being only an ideal situation. These unbalanced current loads can have significant influence on the AC interference levels in underground metallic structures.

Different energization conditions on the phase wire are expressed using the following quality factors, based on symmetrical components of the current phasors: negative-sequence coefficient (k_I^-), zero-sequence coefficient (k_I^0) and total unbalance coefficient (k_I): [7]

$$k_I^- = \frac{I_-}{I_+}\,[\%] \qquad (1)$$

$$k_I^0 = \frac{I_0}{I_+}\,[\%] \qquad (2)$$

$$k_I = k_I^- + k_I^0\,[\%] \qquad (3)$$

The statistical analyses [1], highlights that levels of unbalanced load currents are situated below 1% in case of very high voltage power lines respectively below 2% in case of HVPL. Usually, this variation is due to zero-sequence components of the currents.

Therefore, the influence of the HVPL unbalanced load operating conditions on the vicinity metallic pipelines was studied, considering a 700A base symmetrical current load.

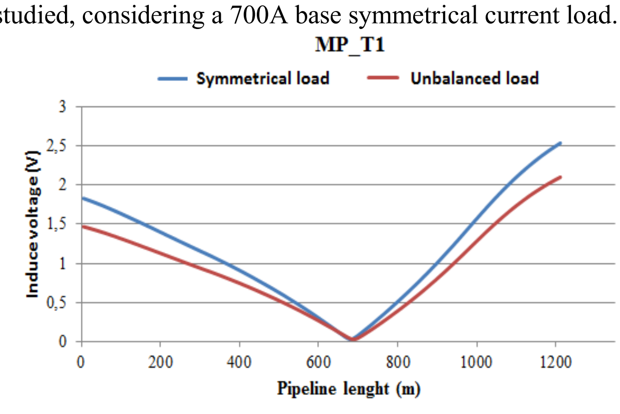


Fig. 8. a) AC Induced voltages along pipeline MP_T1 in case of unbalanced current load

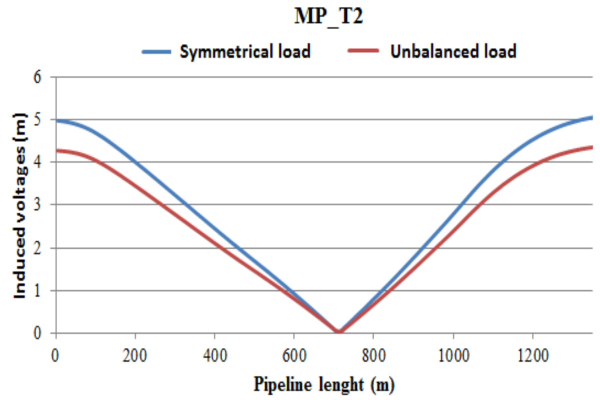


Fig. 8. b) AC Induced voltages along pipeline MP_T2 in case of unbalanced current load

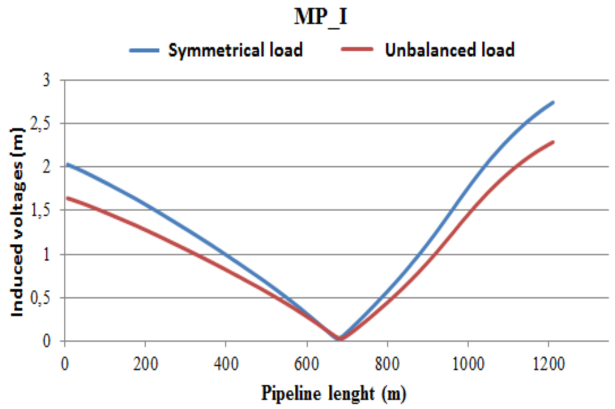


Fig. 8. c) AC Induced voltages along pipeline MP_I in case of unbalanced current load

In correlation with Fig.8 the obtained results emphasizes the fact that in case of a 2% unbalanced load currents, the metallic structures MP_1, MP_T2 and MP_I leads to a 10% decreasing of the induced voltages.

While in case of MP_T3, the AC induces voltages record an 11% increasing of their values. This major increase is due to positioning of the MP_T3 on the other side of HVPL and therefore this leads to a different orientation regarding the phase sequences (Fig. 9).

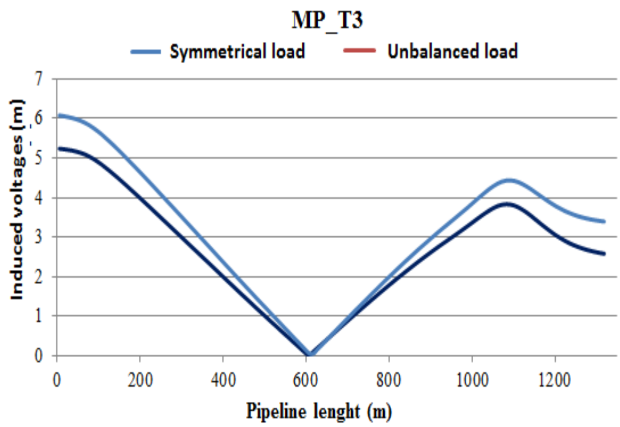


Fig. 9. AC Induced voltages along pipeline MP_T3 in case of unbalanced current load

In comparison with symmetrical load where phase-sequence had almost no influence, in case of unbalance-currents situations, it has a significant effect on induced voltage variation.

C. *Phase-to-Ground Fault Operating Condition*

If a phase-to-ground fault appears far away from the common distribution corridor, so that the conductive coupling between HVPL and MP can be neglected as well as in steady-state operating conditions.

During the fault condition, a current of 5000A is injected by one for each phase.

In this case, the classical "V" curve is obtained more explicitly, because the influence of the generated electromagnetic field of the unfaulted phases is negligible in comparison with the faulted phase. [19-21]

The maximum value of the induced values varies with around 26% regarding to position of faulted phase regarding measuring points (Fig. 10).

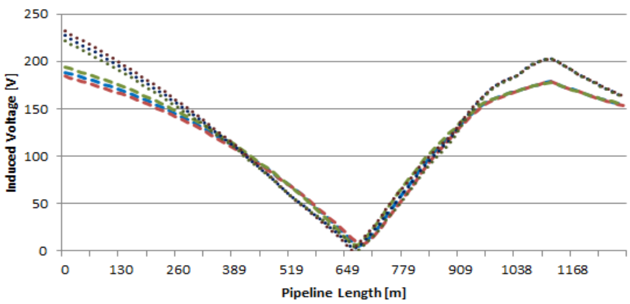


Fig. 10. AC Induced Voltages along metallic pipeline, in case of phase-to-ground operating condition

In case of these extreme conditions, the induced voltages in the metallic structures generate dangerous situations from corrosion and personal safety point of view, and also proper mitigation measures are imposed (e.g. mitigation wires, grounding electrodes).

Most national regulations consider that safety measures have to be taken when the voltages pipeline exceed 50-60V under steady state conditions.

During HV faults to the earth, much higher voltages are admissible. This is because the fault produces a short duration stress and the admissible voltage depends on the stress duration.

Risks due to faults are limited because of the low incidence of faults and the low probability that somebody will be in contact with the pipeline at the very moment when the danger level is exceeded [1, 7, 8].

V. ON-SITE MEASUREMENTS OF THE AC INDUCED VOLTAGES

To verify the accuracy of the induced voltages computed values a comparison with the on-site measured values was done. The practical measurements was performed for pipelines MP_T2 and MP_T3, using $Cu/CuSO_4$ measuring electrode right to points A and B (Fig.1).

Fig. 11 present the variation of the induced voltages in case of MP_T2 and MP_T3, regarding the measuring zinc electrode placed in points A and B, recorder with an oscilloscope.

The above mentioned pipe-to-earth potential measurements on studied HVPL-MP interference problem the help of Pipeline Diagnose Laboratory from the Romanian Natural Gas Transmission System (Fig. 11).

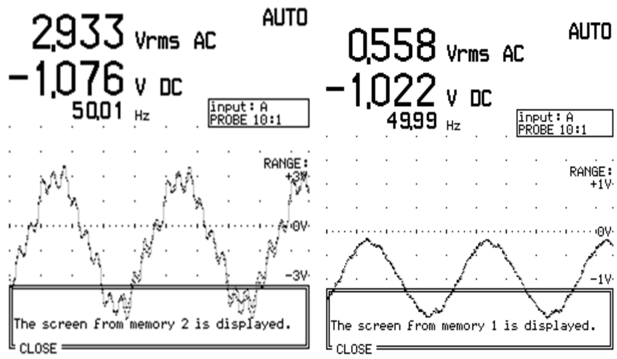


Fig. 11. Measured AC induced voltages right to points A and B

Accordingly to Fig. 11 the measured values of induced voltages are within the range of values computed with the CDEGS software.

VI. CURRENT DENSITIES AT COATING HOLIDAYS

The risk of AC corrosion of the metallic structures is linked with the pipeline isolation defects, which might occur, for instance during construction work.

From an electrical point of view, coating holidays can be seen as a small, high-impedance AC earthing system connected to the MP. If the coating holiday size exceeds a certain dimension, likelihood corrosion risk neutralizes according to the relevant current density. [16-18]

Starting from the resistivity of a circular coating holiday computation formula (d is the diameter of circular coating holiday and ρ is the specific soil resistivity):

$$R = \frac{\rho}{4d}(1 + 2/\pi \cdot \arctan(d/4h)) \qquad (4)$$

the current densities at assumed coating holidays, for evaluated induced pipeline voltages, can be calculated.

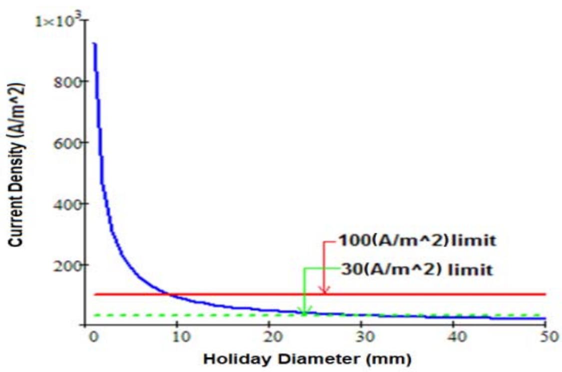


Fig. 12. Current densities at coating holidays for variable coating holiday diameters (the considered AC induced voltages: 4V)

Fig. 12 highlights that in case of coating holidays with smaller diameters, the current densities are considerably higher.

Based on actual investigation in the field of AC corrosion, as well as to the actual European technical specifications the AC corrosion risk can already be expected from current densities at coating holidays among 30 A/m^2. [7]

For current densities between 30 A/m^2 and 100 A/m^2 there exists medium AC corrosion likelihood. For current densities > 100 A/m^2 there is a very high A/m^2 corrosion likelihood.

VII. CONCLUSIONS

The electromagnetic interference problem between a HVPL and a stream gas pipeline, from the Romanian Natural Gas Transmission System is studied in a companion paper. The analysis of presented HVPL-MP interference problem, for different power line operating conditions, has outlined the situations when the induced voltages generates dangerous situations from corrosion and personal safety point of view.

The paper studies the variation of induced currents and voltages for different symmetrical and unbalanced HVPL current loads corresponding to normal operating conditions and also the influence of different HVPL phase sequences and phase transposition.

According to the evaluated induced voltage levels, the authors identify the pipeline sections which present a potentially danger from corrosion and personal safety point of view and also offer important data in case of choosing proper mitigation measures.

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REFERENCES

[1] *** "Guide on the Influence of high voltage a.c. power systems on metallic pipelines", Working Group 36.02, CIGRE, 1995.

[2] Dan D. Micu, L. Czumbil., G.C. Christoforidis and A. Ceclan, "Layer recurrent neural network solution for an electromagnetic interference problem", *IEEE Transaction on Magnetics*, vol. 47, no. 5, pp. 1410-1413, 2011.

[3] K. Budnik, and W. Machczynski, "AC corrosion computer simulation as an element of pipeline system integrity process", *International Gas Union World Gas Conference Papers*, Buenos Aries, Argentina, 5-9 October, 2009.

[4] Dan D. Micu, Iosif Lingvay, Andrei Ceclan, Emil Simion, "Computation of the induced AC potential on gas pipelines for complex rights-of-way configurations", *International conference on advancements of medicine and health care through technology, MEDITECH 2007*, 27-29 sept. 2007, Acta Electrotehnica, vol. 48, nr. 4, pp. 343-347, 2007.

[5] L. Qi, H. Yuan, Y. Wu, and X. Cui, "Calculation of overvoltage on nearby underground metal pipeline due to the lightning strike on UHV AC transmission line tower", *Electric Power Systems Research*, vol. 94, pp. 54-63, 2013.

[6] Dan D. Micu, Andrei Ceclan, Iosif Lingvay, Emil Simion, "Numerical interpolation methods applied in electromagnetic interference problems", *ICREPQ'08, International Conference on Renewable Energies and Power Quality*, Santander, 12-14 March 2008, CD- Paper 283, 2008.

[7] *** "CEN/TS15280: Evaluation of a.c. corrosion likelihood of buried pipelines - Application to cathodically protected pipelines", CEN, 2006.

[8] *** "prEN 50443: effects of electromagnetic interference on pipelines cased by high voltage a.c. railway systems and/or high voltage a.c. power supply systems", CENELEC, Jan. 2011.

[9] Dan D. Micu, A. Ceclan, E. Simion, L. Cret, "Numerical methods applied in electrotechnical applications", *Journal of Electrical and Electronics Engineering*, pp. 43-47, 2005.

[10] J. Ma, and F.P. Dawalibi, "Recent Advances in Electromagnetic Analysis in Common Corridors", *4th Asia-Pacific Conference on Environmental Electromagnetic (CEEM),* Dalian, China, August 1-4, 2006, pp. 409-418.

[11] Dan D. Micu, I. Lingvay, C. Lingvay, L. Darabant, and A. Ceclan, "Numerical evaluation of induced voltages in the metallic underground pipelines, *Revue Roumaine des Sciences Techniques serie Électrotechnique et Énergetique*, vol. 54, no. 2, pp.175-184, 2009.

[12] M. Nassereddine, and A. Hellany, "AC interference study on pipeline: The impact of the OHEW under full load and fault current", *International Conference on Computer and Electrical Engineering*, Dubai, United Arab Emirates, December 28-30, 2009.

[13] A.H. Al-Badi, S. M. Ghania, and E. F. EL-Saadany, "Prediction of Metallic Conductor Voltage owing to Electromagnetic Coupling Using Neural Fuzzy Modeling", *IEEE Transactions on Power Delivery*, vol. 24, no. 1, pp. 319-327, 2009.

[14] Dan D. Micu, Emil Simion, Dan Micu, Andrei Ceclan, "Numerical Methods for Induced Voltage Evaluation in Electromagnetic Interference Problems", *9th International Conference, Electric Power Quality and Utilisation*, Barcelona, 9-11 October 2007.

[15] D. Caulker, H. Ahmad, and M.S. Mohamed Ali, "Effect of Lightning Induced Voltages on Gas Pipelines using ATP-EMPT Program", *2nd International Conference on Power and Energy (PECon)*, pp. 393-398, Johor Baharu, Malaysia, 1-3 December, 2008.

[16] G. Christoforidis, and D. Labridis, "Inductive Interference on pipelines buried in multilayer soil due to magnetic fields from nearby faulted power lines", *IEEE Transaction on Electromagnetic Compatibility*, vol. 47, no. 2, pp. 254-262, 2005.

[17] F.A. Brichau, and J. Deconinck, „A Numerical Model for Cathodic Protection of Buried Pipes", *Corossion*, vol. 50, no.1, pp. 39-49, 1994.

[18] R. Braunstein, E. Schmautzer, and M. Oelz, "Impacts of inductive and conductive interference due to high-voltage lines on coating holidays of isolated metallic pipelines", *21st International Conference on Electricity Distribution*, Frankfurt, Germany, June 2011.

[19] L. Cret, M. Plesa, D. Duma, R.V. Ciupa: "Magnetic Coils Design for Localized Simulation", *IFMBE Proceedings*, vol.16, pp.665-668, 2007.

[20] A.Z. El Dein, "Magnetic-field calculation under EHV transmission lines for more realistic cases", *IEEE Transactions on Power Delivery* vol. 24, no. 4, pp. 2214-2222, 2009.

[21] H. Zhang, G. G. Karady, and J. Hunt, "Effect of various parameters on the inductive induced voltage and current on pipelines", *IEEE PES General Meeting*, July 2011.