Electromagnetic Interference Issues   
in Case of Metallic Structures

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*Abstract*—The paper approaches some electromagnetic interference problems that can occur between an existing high voltage power line and a newly designed stream gas pipeline. Induced currents and voltages are computed for different steady state power line symmetrical and unbalanced current loads. Pipelines AC corrosion likelihood is evaluated and proper mitigation measures are proposed.

Keywords—electromagnetic interference; underground metallic pipelines; induced currents and voltages; mitigation techniques

# Introduction

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. In these cases, metallic pipelines (MP) are exposed to the effects of induced AC currents and voltages, which can be dangerous for both operating personnel, which could be exposed to electrocution, and pipeline structural integrity due to AC corrosion [1-7].

To provide personal safety, international guides and standards limit the admissible value of induced voltages in underground or above ground pipelines [8, 9]. Table I presents the limits for the induced AC voltages, according to maximum allowed current flow through human body:

1. Limits for Interference Voltages versus Earth   
   or Across the Joints Related to Danger to People

|  |  |
| --- | --- |
| **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 |

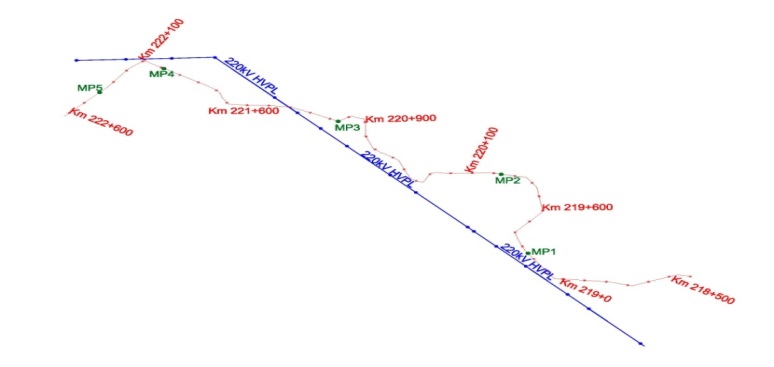
On the other hand, since even the highest quality coatings have defects, allowing an exchange of current between the metal pipeline and the surrounding soil, in order to reduce AC corrosion likelihood existing guides suggest a more restrictive induced voltage limitation as follows:

* 10V where the local soil resistivity is greater than 25 Ωm;
* 4 V where the local soil resistivity is less than 25 Ω·m.

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. Therefore, the aim of this paper is to evaluate pipeline corrosion likelihood and to identify the proper mitigation solutions, for a real case study from Romania, based on computed induced AC voltage values.

# Studied Electromagnetic Interference Problem

A newly designed underground metallic gas pipeline, from the Romanian Natural Gas Transmission System, will be placed in the same distribution corridor with an existing single circuit 220kV/50Hz overhead high voltage power line. The common right-of-way will have an approximate length of 4 km, and the pipeline will be buried at 1.1 m (see fig. 1).



1. HVPL-MP Common distribution corridor.

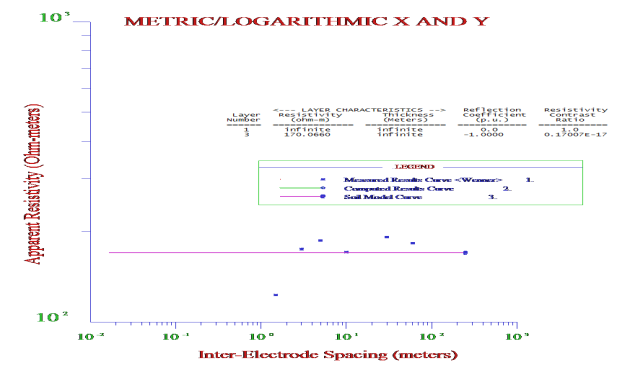
In order to identify hazardous zones and appropriate protection methods along pipeline length, capacitive coupling for the above ground zone and inductive coupling for the entire common right-of-way are evaluated. [1-5]

# Soil Resistivity Analysis

To increase evaluation accuracy, soil resistivity measurements were done in five different locations along the common distribution corridor.

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.

A dedicated software application was used to determine the equivalent homogeneous soil model for onsite soil resistivity measurements, as shown in fig. 2.



1. Equivalent electrical circuit model.

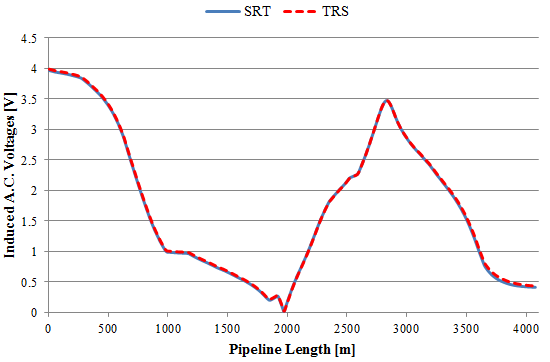
# Evaluation of Induced Currents and Voltages

To evaluate induced voltage along pipeline length a hybrid method presented in [1] is used. The proposed method combines finite element calculation and equivalent circuit model in order to evaluate the inductive and capacitive couplings.

The first step of the method is to construct a 2D model representing the cross section of the studied interference problem. The second step is to analyze it using finite element calculation software, in order to evaluate the self and mutual impedances between all conductors of the problem. The benefit of such approach is that complex geometries can be taken into consideration and the exact structure of the soil is not ignored or simplified. Then, a generalized equivalent electric circuit is constructed. To solve this electrical circuit model a suitable method presented in [1-4] has been applied. Pipe to earth measurements on similar interference problems had been made with the help of Pipeline Diagnose Laboratory from the Romanian Natural Gas Transmission System to validate the presented method.

## Equivalent circuit approach

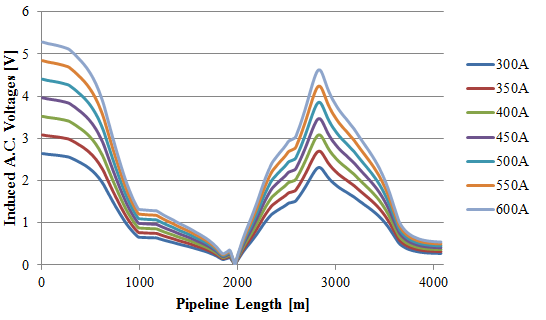
Initially, the electromagnetic interference analysis on the metallic pipeline was carried out without the proposed interference mitigation systems and during power lines steady state conditions with a symmetrical 450A current load. Both direct and invers phase sequences were investigated, obtaining a 0.5% difference between evaluated induced voltage values:



1. Induced voltages along pipeline length.

Figure 3 emphasizes the pipeline segments were the induced voltages records the highest values. First of this segments is situated at the left end of the pipeline and the other segment is where MP under-cross de HVPL (around 2800m from the pipeline left end). A local minimum is obtained at segment situated around 1900m from the common right-of-way beginning. Further on, especially these segments will be investigated regarding the values of induced voltage.

Romanian statistics mentioned that, power flow through an 220kV power line varies between 45–75MW. Therefore, to investigate the induced AC potential levels, that can occur for different power flows, the symmetrical current load on HVPL was considered in the range of 300-600A.



1. Induced voltages along pipeline, in case of different power line symmetrical current loads.

In correlation with figure 3, the levels of the induced voltages in metallic pipeline increases with the value of current load. In these conditions and with an appropriate mitigation solution of MP, the corrosion likelihood in the metallic structure is reduced. The critical values of the induced voltages, regarding the start of electrochemical corrosion reaction, are around 1200mV [8].

## 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 pipelines.

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 (), zero-sequence coefficient () and total unbalance coefficient () [10-11]:

[%];  [%];  [%] 

Considering a 2% total unbalance coefficient, the induced voltages in underground metallic pipeline was computed for different phase sequences; Table II presents the unbalanced current loads for each HVPL phase wire (450A symmetrical current load).

1. Values of the Phase Currents

|  |  |  |
| --- | --- | --- |
| **Phase Wire** | **Current load [A]** | **Current phase [deg.]** |
| Phase R | 459 | 0 |
| Phase S | 445.5 | -120 |
| Phase T | 445.5 | 120 |

## 

1. Induced voltages in case of unbalanced current loads.

In comparison with symetrical load where phase-sequence had almost no influence [12], in case of unbalance-currents situations, it has a significant effect on induced voltage variation (fig. 5). The worse case was recorded when the HVPL has the heavely loaded phase on the same side with the pipeline (TSR sequence).

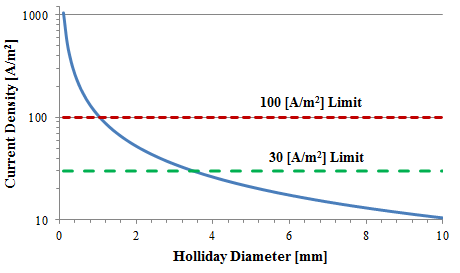
# Current densities at coating holidays

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. [13]

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):

 

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



1. Current densities at coating holidays (for a 3.5V induced voltage).

Fig. 6 highlights the fact that in case of coating holidays with smaller diameters, the current densities are considerably higher.

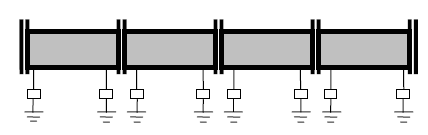
Based on actual investigation in the field of AC corrosion, as well as to the actual European technical specifications the AC corrosion risk can already be expected from current densities at coating holidays among 30 A/m2 [8]. For current densities between 30 A/m2 and 100 A/m2 there exists medium AC corrosion likelihood. For current densities > 100 A/m2 there is a very high A/m2 corrosion likelihood [14].

# Mitigation Measures

This paper proposes a comparison between some mitigation methods in order to identify appropriate induced voltages attenuation technique for the presented practical case. Insulating joints and cancellation wire mitigation techniques are investigated.

## Insulating joints

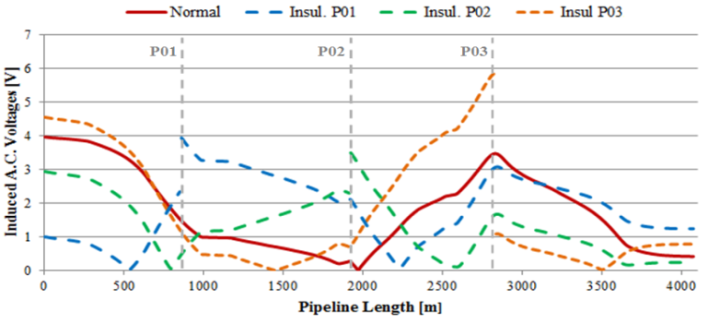
Insulating joints divide the pipeline into several electrically isolated parts so that induced voltage cannot reach high levels. Local ground is then connected to the pipeline at each side of the insulating joint. Each earthing electrode is connected to the pipeline through a surge diverter, which operates only when the voltage on the pipeline is higher than its breakdown level. With this method, the pipeline is protected from stray current that can cause corrosion and cathodic protection currents are prevented from leaking out [12-15].



1. Induced voltages in case of unbalanced current loads.

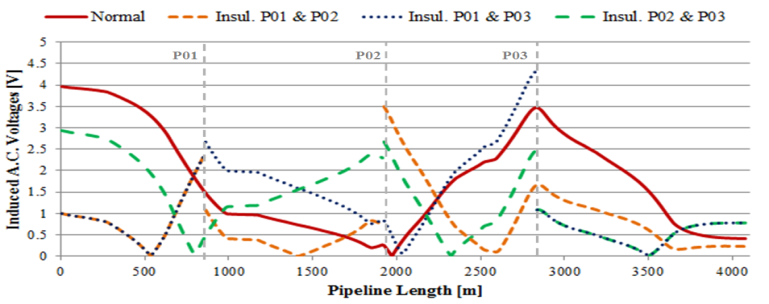
In order to reduce the AC induced voltages in MP, different locations of the insulating joints was considererd along pipeline length.

In a first step, the atenuation of the AC interferences was analised only for one insulating joint. This was considered connected to the MP, in points situated at around 850m (P01), 1900m (P02) respectively 2800m (P03, HVPL undercrossing), from the beginning of the common right of way (see fig. 8).



1. Induced Voltages along the MP in case of just one insulating joint.

When the insulating joint was located at point P02 an 14% attenuation of the maximum induced voltage value and a new distribution of voltage peaks along MP length, were obtained. On the other hand, a positioning at the HVPL undercrossing point (point P3) could lead to an increase of the AC interference (Fig. 8).



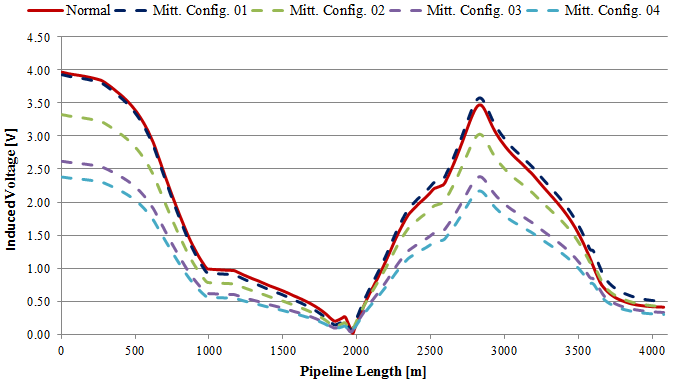
1. Induced Voltages along the MP in case of using two insulating joint.

In a second step of the analysis the pipeline was divided into three electrically separated parts by two insulating joints (figure 9). The more efficient mitigation measure was obtained in case of P03 and P02 simultaneous isolation points (26%).

## Cancellation (mitigation) wire:

This mitigation technique consists in a long buried wire parallel to the transmission line, often on the side of the transmission line opposite to the pipeline. With proper positioning, the voltages induced in the wire are out-of-phase with voltages induced into the pipeline. [5]

Four different cases were considered regarding the connection between mitigation wire and the MP. Case 1 means the situation when the cancellation wire has no connection with MP. Case 2 means that mitigation wire is connected at both MP ends and at point P03. During Case 3 and Case 4, the MP is connected at every 500m respectively at 100m to the mitigation conductor.



1. Induced Voltages along the MP using cancelation wires

According to figure 10, the mitigation solution proposed in case 4, lead to a 38% attenuation of the AC induced voltage values, at left end of the metallic structure, which could be considered as a significant reduction.

A comparative analysis of the results, presented in figures 8-10, reveal the fact that the mitigation system with insulating joints has a superior performance compared to a system with mitigation wire.

A combined mitigation technique (insulating joint and cancellation wires) could be very efficient in reducing AC induced voltages in metallic structures.

Figure 11 highlight the evaluated induced voltage along the pipeline length when the combined insulating joints – cancelation wire mitigation method is applied: and insulating joints at points P02 and P03 and mitigation wires connected to the MP at every 100m. The attenuation of the AC interference presents an average value of 48%.

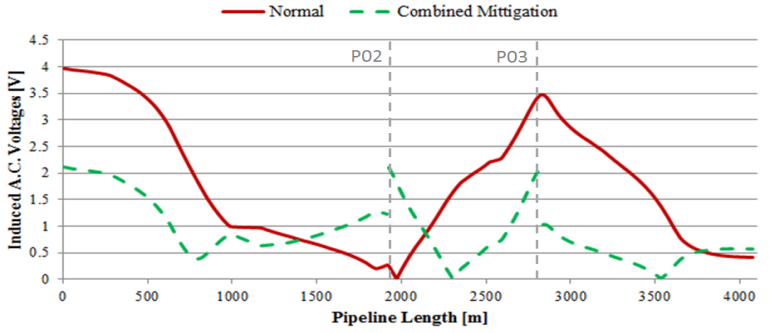


Fig. 11. Induced voltages for using insulating joints with cancellation wires

# Conclusions

The paper studies the induced voltage levels in the underground metallic pipeline when different soil resistivity models are considered along the common distribution corridor.

The above mentioned mitigation methods had been tested and validated by pipe-to-earth potential measurements on a similar HVPL-MP interference problem with the help of Pipeline Diagnose Laboratory from the Romanian Natural Gas Transmission System.

##### Acknowledgment

This paper was supported by the project TE 253/2010 CNCSIS project – “Modeling, Prediction and Design Solutions, with Maximum Effectiveness, for Reducing the Impact of Stray Currents on Underground Metallic Gas Pipelines”, No. 34/2010.

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