Numerical Analysis of the Corrosion of Buried Pipes near High Voltage Transmission Lines

Darío Mateo Arango Angarita
Dept. of Electrical Engineering
Universidad Nacional Colombia
Bogotá, Colombia
dmarangoa@unal.edu.co

Daniel Vargas Medina
Dept. of Electrical Engineering
Universidad Nacional Colombia
Bogotá, Colombia
davargasme@unal.edu.co

Javier Leonardo Araque Quijano
Dept. of Electrical Engineering
Universidad Nacional Colombia
Bogotá, Colombia
jlaraqueq@unal.edu.co

***Abstract*—We present the multi-physical analysis of the induction-corrosion process undergone by a buried pipe subject to electromagnetic induction from a nearby High Voltage Transmission Line (HVTL). The scenario analyzed models a typical situation found in Colombia by using realistic characteristics of the pipe, the HVTL, and environmental parameters such as soil resistivity. The results presented provide a quantitative view of the corrosion process and constitute a useful tool for the analysis and design of the increasingly common situation of pipelines running near HVTLs.**

***Index Terms*—Buried pipelines, corrosion, electromagnetic fields, HVTL, multi-physics.**

I. INTRODUCTION

The rise in the energy demand, the high cost of rights-of-ways and environmental regulations have compelled many companies to use the same pathways for both high voltage transmission lines and pipelines, which has increased the parallelism between these structures through long distances. Such extended parallelism is known to increase the corrosion rate of pipelines; hence the present trend will likely increase the risk of negative environmental, health and economic impacts due to the leak of pipe contents. Due to the relevance of the phenomenon of corrosion, its study remains an area of active research [1]-[11], though to the best of our knowledge, these deal separately with the electromagnetic and corrosion phenomena.

Characteristics of the line such as geometry, nominal voltage/current level, environmental factors such as ground resistance and temperature [5],[10], and pipeline material and coating [1], are variables of interest that affect the underlying mechanism of electromagnetic induction. The complex interplay of parameters in several physical domains, and the need of an accurate prediction tool for analysis and design, makes this problem very well suited for numerical multi-physical analysis.

In this work, the COMSOL package, based on the Finite Element Method (FEM), was used to perform an integrated analysis of the induction-corrosion phenomenon by coupling the electromagnetic and electrochemical domains in the analysis of a realistic scenario. The simulation parameters are based on a case study that includes the geometry of HVTLs used typically in Colombia and the corresponding soil parameters. Results show the material loss (corrosion) due the electromagnetic induction in the pipeline.

II. SCENARIO UNDER ANALYSIS

The scenario analyzed consists of a simplified 2-D representation of a HVTL tower, its corresponding power and guard lines, its grounding, and the pipe buried in the surrounding soil, as shown in Fig. 1. Table I summarizes the characteristics of the materials considered in the simulation.

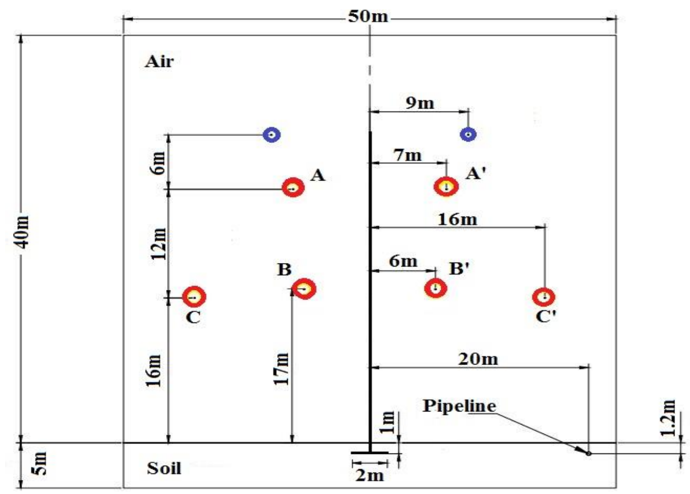

Fig 1. Quoted diagram of the scenario analyzed.

TABLE I
MATERIAL VALUES FOR SIMULATION

Material	σ [Sm^{-1}]	μ_r	ε_r	E_{eq} [V]
Air	0	1	1,0006	-
Soil	0.01	1	40	-
Copper	5,998e7	1	1	-0,38
Pipeline	8.33e6	250	1	-0,859

III. SYSTEM EQUATIONS

A. Induction Analysis

To model the electrical effect in the pipeline due to the HVTL presence, two types of excitation are considered: a three-phase voltage of 500kV and a balanced current of 2000A at 60Hz (Fig. 1). These conditions are typical in HVTL with bundles of conductors. The equations used to model such effects are:

$$\nabla x H = J + \epsilon_O \epsilon_r \frac{\partial E}{\partial t}, \quad (1)$$

$$J = \sigma E \,, \quad (2)$$

where E, H and J are the electric, magnetic and current density fields, $\epsilon_O \epsilon_r$ and σ are the is the electrical permittivity and conductivity of the medium respectively. The initial conditions were assumed as 0V for all elements. Also, the boundary of the domain and the tower are considered as ground.

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B. Corrosion Analysis

The voltage induced in the pipeline affects the corrosion mechanism as follows:

$$\eta = \varphi_{ext} - \varphi_l - E_{eq}, \tag{3}$$

where φ_{ext} is the external potential (the one induced in the electrode), φ_l is the electrolyte potential, and E_{eq} is the equilibrium potential. The Tafel equations were employed to model the anodic (i_a) and cathodic (i_c) current of the electrodes:

$$i_c = i_{oc} 10^{\frac{\eta}{b_c}}, \tag{4}$$

$$i_a = i_{oa} 10^{\frac{\eta}{b_a}}, \tag{5}$$

$$\frac{\partial c_{d,j}}{\partial t} = \sum_m R_{d,j,m}. \tag{6}$$

with i_{oa}=2.35m57m A/m^2, i_{oc}=14,57m A/m^2, b_a = 0.118V and b_c = –0.207V. Equation (6) shows how the material concentration $c_{d,j}$ changes due to the reaction rate R, which satisfies the following relation in the electrodes:

$$R_{d,j} = \frac{-\nu_{d,j} i_{el}}{2F}. \tag{7}$$

Where F is the Faraday constant, i_{el} is the current of the electrode (i_a or i_c) and $\nu_{d,j}$ is the stoichiometric coefficient in the reduction reaction.

IV. Results

The voltage induced in the pipeline is sinusoidal with an RMS value of 176*V*. The corrosion current density in the pipeline surface shows a maximum value of 3.76 *A/m²* and an average value of 1.2 *A/m²*. The material loss after 10,000 hours is between 0.8*mm* and 1.4*mm* as shown in Fig. 2.

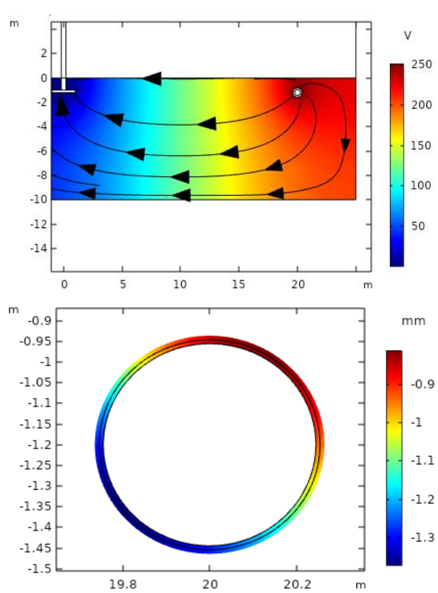

Fig. 2. Voltage induced in the soil around the pipeline and illustration of the flow of corrosion current (top) and surface displacement in the pipeline after 10.000 h (bottom).

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