# SAFETY OF PIPELINES IN CLOSE PROXIMITY TO ELECTRIC TRANSMISSION LINES

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**Abstract -- AC interference from high voltage power lines can constitute an electric shock hazard and a threat to equipment integrity during both load and fault conditions. Mitigation systems are usually installed to reduce the touch voltages so that the nearby metallic utilities are safe. This paper discusses the states of the touch and step voltages for a few typical right-of-way systems under load and fault conditions. The effects of a typical mitigation system on the inductive interference levels are also studied. The results presented in this paper clearly illustrate the safety behavior of pipelines subjected to electromagnetic interference from neighboring electrical networks and the effectiveness of mitigation.**

**Index Terms – AC Interference, safety, pipelines, touch voltages, step voltages, potentials, induced voltages, mitigation.**

## I. INTRODUCTION

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 metallic structures connected to the pipeline or simply standing nearby. Furthermore, damage to the pipeline coating, insulating flanges, rectifiers or even direct damage to the pipeline's wall itself can occur.

In recent years, study of interference effects from AC power lines in pipelines, railways, communications lines and other such structures and mitigating AC voltages induced in pipelines has resulted in numerous research reports, papers and standards [1-18]. These references show that the determination of interference effects in a typical right-of-way is a complex procedure requiring not only a good knowledge of conductor layout, power line and pipeline electrical characteristics and electrical system parameters, but also an accurate representation of the soil structure [3].

Mitigation systems are designed to reduce touch voltages and coating stress voltages to acceptable levels during power line load and fault conditions. Lumped grounding, cancellation wires and gradient control wires are commonly used mitigation approaches. Among them, the gradient control method is the most effective and cost-efficient.

This paper discusses the safety states of three simple right-of-way scenarios during load and fault conditions. Interference effects and the performance of mitigation systems are illustrated for pipelines which are both parallel and non-parallel to the power lines.

## II. DESCRIPTION OF THE PROBLEM

Figure 1 presents the complete model of a right-of-way network (Model 1) for the case of a pipeline parallel to a transmission line (T/L) under fault conditions. The network consists of one transmission line and one pipeline. The modeled portion of the T/L is about 10 km (9620 m) long. For simplicity, only one phase conductor and the shield wire have been modeled. The phase conductor is 27 m above grade. The shield wire, an optical fiber conductor, is parallel to the phase conductor and is 35 m above grade. Its diameter is 12.7 mm; its relative resistivity (with respect to copper) is 1.67 and relative permeability (with respect to free space) is 1. The shield wire is connected to the neutral point at each end through an appropriate impedance of 10 ohm to simulate a long T/L line. The T/L span length is 400 m. Each span is delineated by a pole structure represented simply as a single vertical wire connecting the shield wire to a 10 m long ground rod approximating the grounding afforded by the pole foundation.

The pipeline is centered length-wise in the corridor and is 40 m away from the T/L center. The pipeline length of exposure is 4400 m and this portion is parallel to the T/L. At each end of the exposure, the pipeline veers away perpendicularly and continues for 1000 m before terminating. The outer diameter of the pipe is 40 cm and its wall thickness is 10 mm. The pipeline is buried 2 m below grade. The relative resistivity of the pipe wall is 12 and its relative permeability is 250. The pipeline's effective coating resistivity is 3,048,781 ohm-m (as computed based on a leakage resistance of 12131.7 ohm-m$^2$ and a thickness of 5 mm). A fault current of 12,500 A is assumed to be flowing from each end of the transmission line during a fault at the central pole of the right-of-way.

For the case of a parallel pipeline under load conditions, two more phase conductors, on each side of the phase conductor in Model 1 are added. The separation distance between adjacent phase conductors is 5 meters. A 1,000 A load current is assumed to be flowing in the 3 phase conductors of the T/L, with phase angles of 0, 120, 240 degrees (Model 2), respectively.

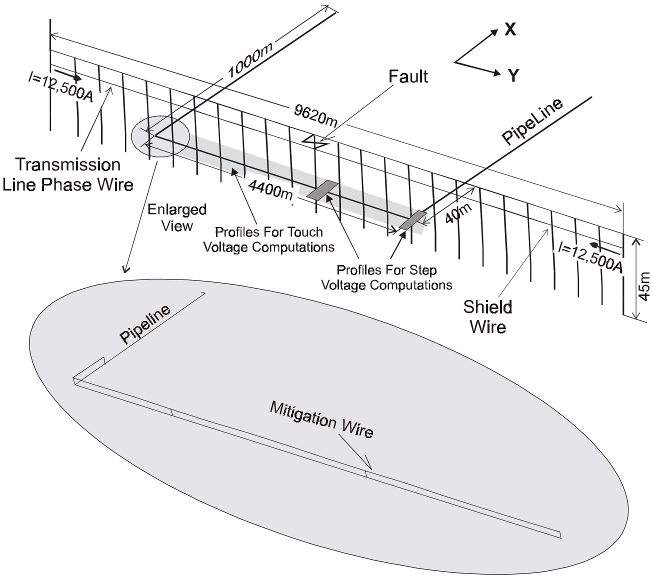


Fig. 1. The completed right-of-way network (Model 1).

For the case of a non-parallel pipeline under fault conditions, Model 1 is used, but the pipeline is rotated 15 degrees with respect to the mid-point along the transmission line. A fault current of 12,500 A is again assumed to be flowing from each end of the transmission line during a fault at mid-point (Model 3).

A highly effective means of mitigating excessive pipeline voltages is the installation of gradient control wires. In this paper, a typical mitigation system is applied to the exposed pipeline for all the cases studied. A bare, continuous, 14 mm diameter conductor is buried at a depth of 1.5 m, with a 1 m horizontal separation from the pipeline, on the side closet to the transmission line. The wire is regularly bonded to the pipeline (every 200 m for the first 400 m at each end and every 400 m for the rest of the middle portion of the pipeline). The gradient control wires not only provide good grounding for the pipeline and thus lower the magnitude of the pipeline potentials, but also raise earth potentials in the vicinity of the pipeline such that the difference in potential between the pipeline and the local earth is reduced. As a result, touch voltages and coating stress voltages are significantly reduced.

## III. METHODOLOGY OF THE STUDY

The field theory approach is used to carry out the study. The field approach is based on electromagnetic theory. It takes into account the inductive, capacitive and conductive interference effects between all the elements in the network in one single step. In order to get results with higher accuracy, a numerical evaluation (Gaussian integration method) of Sommerfeld integrals is used instead of an analytic approximation [19-22].

For the purpose of computing touch voltages in the vicinity of the pipeline, 11 profiles on the earth surface above the pipeline are specified, starting at one end of the pipeline and ending at the other (the length of each profile is 4600 m). The separation distance between two adjacent profiles is 1 m (see Figure 1). The touch voltage computed here is the difference between the earth potential at an observation point and the ground potential rise (GPR) of a conductor segment which results in the greatest touch voltage and which is partially or wholly within a 6 m radius of the observation point (feet location). This 6 m radius is selected to account for the possibility of a ground metallic structure extending up to 6 m from its ground bonding point. First, earth surface potentials were calculated along the profiles, then subtracted, accounting for phase angle, from the potential rise of the pipeline segment described above.

For the step voltage computation, two more sets of profiles on the earth surface are specified. The first set consists of 6 profiles which are perpendicular to the pipeline and are located at the center of the pipeline (fault location). The other set has 5 profiles, which are located at one bending point of the pipeline (see Figure 1). The step voltages are computed at each observation point with the maximum difference in potentials between that point and any other observation point within a 1 m stride of that point.

## IV. ANALYSIS AND DISCUSSION

This study was performed using the field-based approach [10]. The threshold values of the safe touch and step voltages, which are used as a criterion in extracting and reporting "unsafe" observation points in a 2D spot plot (Figures 3 and 4), are computed for a backup fault clearing time of 0.5 seconds and a 100 ohm-m uniform soil. The safe touch and step voltages are 189.7 V and 266.6 V, respectively.

### *A. Pipeline Parallel To Transmission Line Under Load Condition*

Figure 2 shows the touch voltages along the pipeline without mitigation, under load conditions. The touch voltage curve is symmetric due to the symmetry of the system, as expected. The minimum touch voltage occurs at the center of the pipeline. This is because, due to the symmetry of the system, the induced EMF in the pipeline on both sides of this point are the same, resulting in a minimum leakage current from the pipeline at this point. Since leakage current is responsible for the potential rise of the pipeline, the pipeline potential is therefore at a minimum at this point. The touch voltage is the difference between the pipeline potential and earth surface potential. Because the earth surface potential is very small (close to 0 V), the touch voltage is actually very close to the pipeline potential. The maximum touch voltage occurs at the two bending points of the pipeline. This is because the strong discontinuity of the EMF at these two points forces a large leakage current from the pipeline, resulting in large pipeline potentials, and therefore large touch voltages at these two points. The maximum touch voltage exceeds 15 V and therefore requires mitigation, according to North American safety standards for load conditions [17, 18].

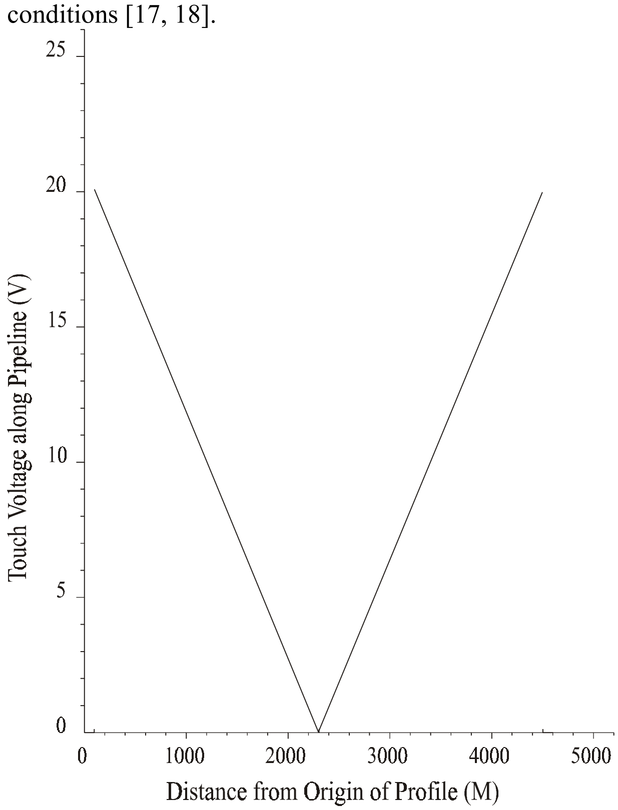


Fig. 2. Touch voltages along the pipeline under load conditions, without mitigation.

It is expected that step voltages are very low because the earth surface potentials are very low under load conditions. In fact, the maximum step voltage is only 0.04 V, occurring at the pipeline bending points. Obviously, it is not a problem in terms of safety.

### B. *Pipeline Parallel To Transmission Line Under Fault Conditions*

Figures 3 and 4 present touch voltages in the area covered by the profiles defined in Figure 1, with and without mitigation, during the fault condition. Figure 5 compares the touch voltages with and without mitigation for the middle profile. Figures 6 and 7 show the step voltages with and without mitigation. From these figures, we can observe the following:

1. The maximum touch voltages, 1793 V without mitigation and 848 V with mitigation, occur at the fault location (this is true also for the maximum step voltage: 64 V without mitigation and 116 V with mitigation.).

2. Touch voltages decrease with increasing distance from the mid-point of the pipeline, but peak at the pipeline bending points because of the longitudinal current discontinuity. They also peak at each tower location, due to the strong conductive interference caused by the current flowing into the earth from each tower. A similar pattern occurs for step voltages.

3. When the mitigation wires are installed, the pipeline touch voltages are tremendously reduced (the worst touch voltage is reduced to 629 V, or by 71%). This is because brings earth and pipe potentials closer to one another, by essentially eliminating the insulating barrier between the two. On the other hand, this considerably increases the flow of current between the pipeline (i.e., its mitigation wire) and the earth, thus increasing step voltages! Indeed, the maximum step voltage becomes 116 V.

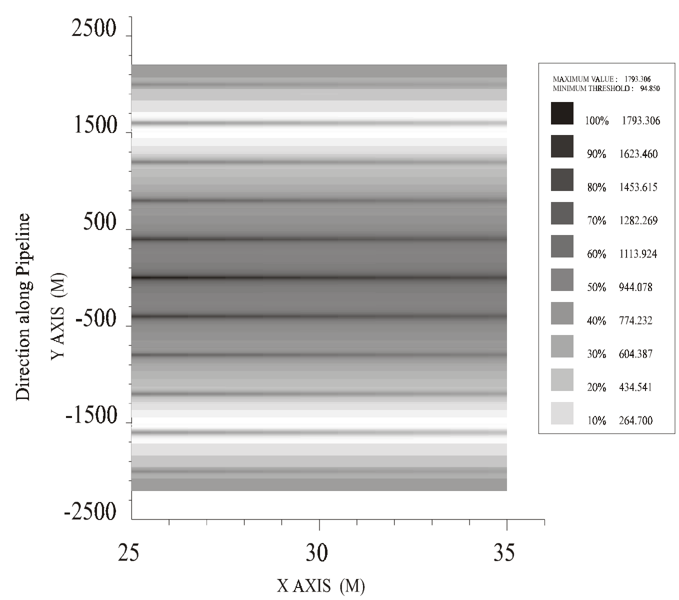


Fig. 3. Touch voltages for the computed profiles under fault condition, without mitigation.

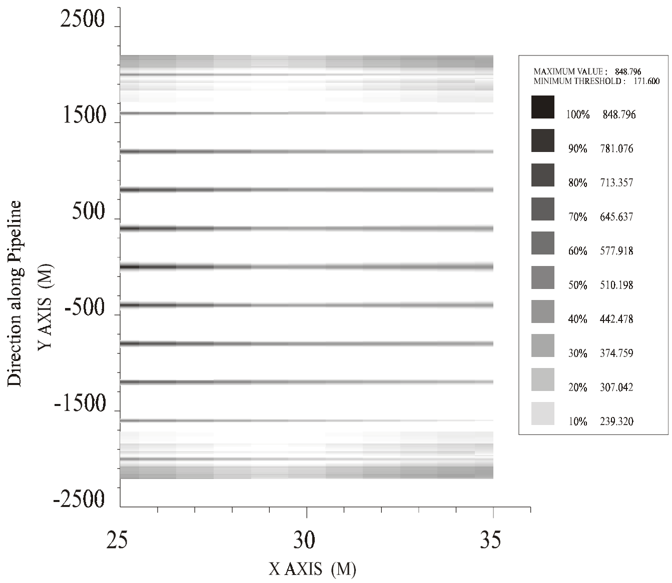


Fig. 4. Touch voltages for the computed profiles under fault condition, with mitigation.

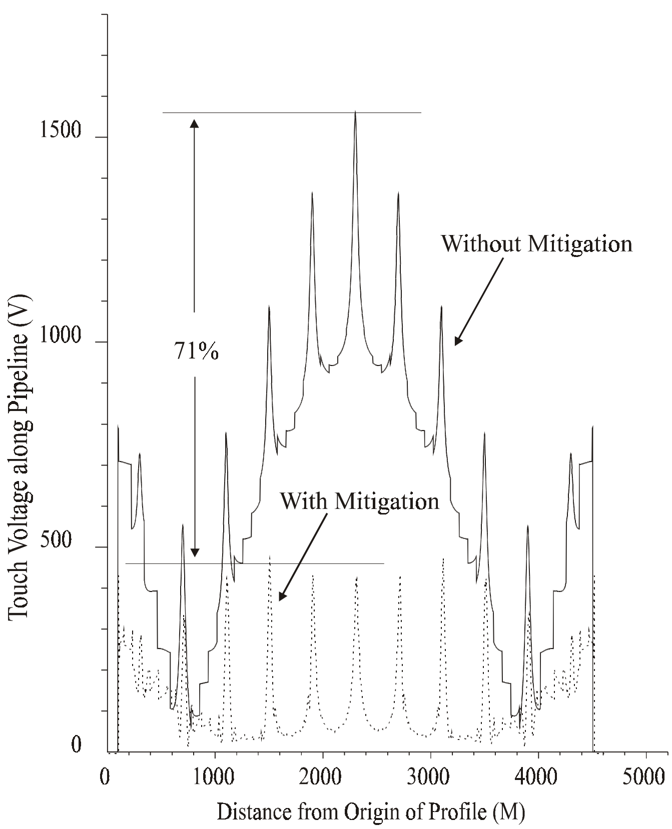


Fig. 5. Touch voltages along the pipeline under fault condition.

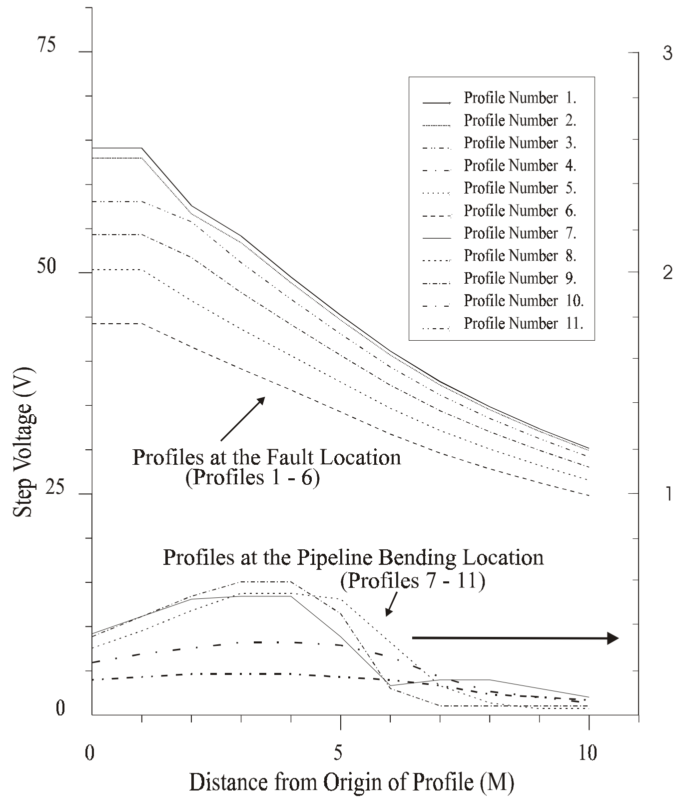


Fig. 6. Step voltages under fault condition, without mitigation.

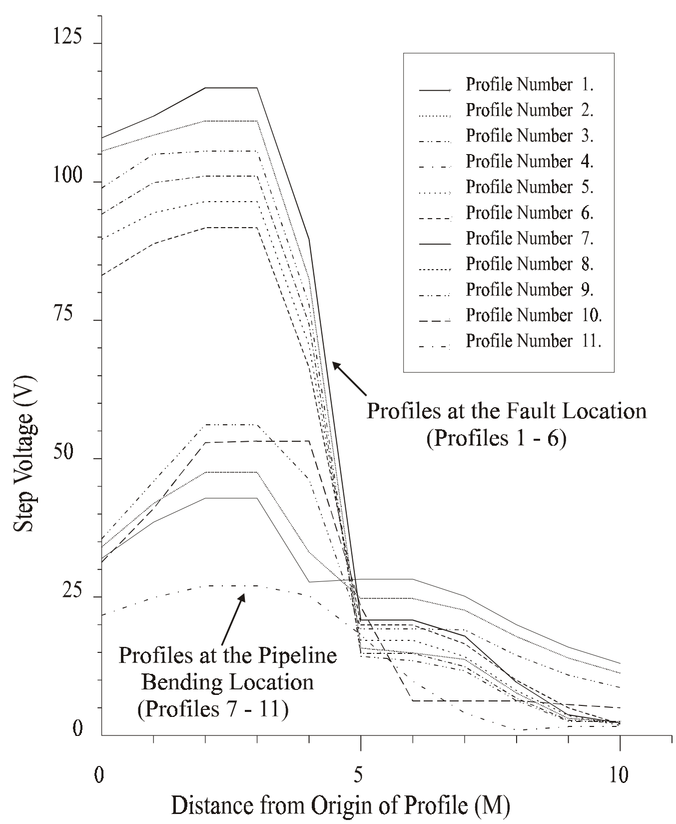


Fig. 7. Step voltages under fault condition, with mitigation.

### C. *Pipeline Intersecting The Transmission Line Under Fault Conditions*

Let us consider the case of the pipeline crossing the transmission line at an angle of 15 degrees (Model 3). Figure 8 compares the touch voltages of the pipeline for the middle profile with and without mitigation during a fault near the crossing location. It clearly indicates that the touch voltage decreases more rapidly with increasing distance from the mid-point of the pipeline compared to the parallel case, because the magnetically induced voltage is significantly reduced, leaving the faulted tower as the primary source of touch voltage (by means of through earth coupling). The worst touch voltage is decreased from 1200 V to 400 V, or by 67%, when the mitigation wires are installed.

The step voltage reaches its maximum at the fault location also. The worst step voltage is increased from 60 V to 108 V when the mitigation wires are installed.

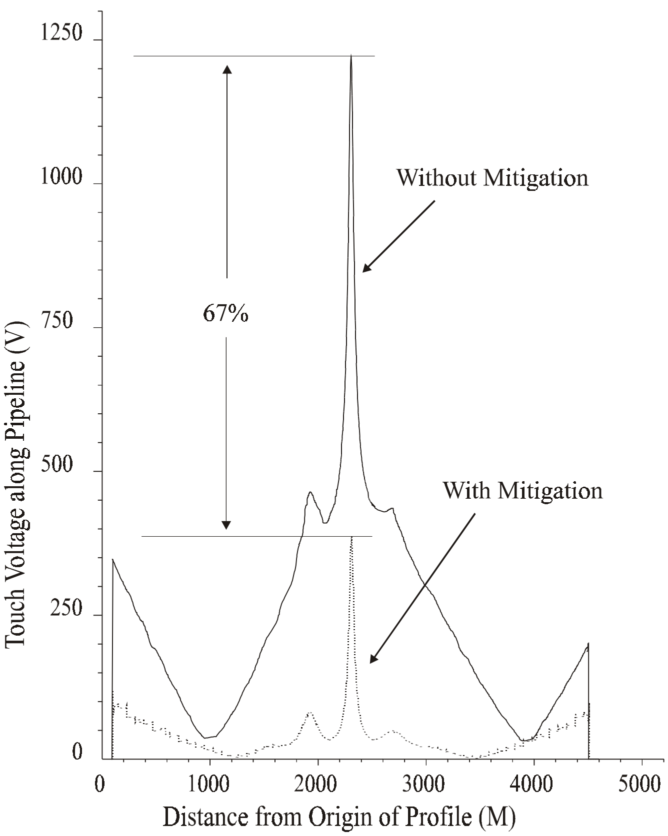


Fig. 8. Touch voltages along the pipeline under fault condition, with crossing pipeline crossing at 15 degrees angle at mid-span of the central span.

## V. CONCLUSIONS

The safety of pipelines in close proximity to transmission lines has been studied. Excessive unsafe touch voltages may exist due to the inductive and conductive interference between the pipeline and the transmission lines. The results presented in this paper reveal the behavior of touch and step voltages for several right-of-way scenarios. The worst touch and step voltages occur at the locations where EMF (or longitudinal current) has the strongest discontinuity, all other things being equal.

The installation of mitigation wires (also known as gradient control wires) can significantly reduce touch voltages by bringing earth and pipeline potentials closer to one another. On the other hand, they tend to increase step voltages. Since the safe step voltage threshold is generally much larger than the safe touch voltage threshold, this increase in voltage often does not represent a problem.

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