Realistic Modelling of HVAC Interference on the Pipelines

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ABSTRACT

The assessment of AC interference levels on metallic pipelines sharing a common utility corridor with overhead electrical power lines is a complex task; which greatly depends on multiple factors such as soil properties, pipeline characteristics, operating voltages, load or fault currents, tower configurations and their locations, as well as the separation of the pipeline and power line. This paper discusses the assessment of AC Interference levels on a buried gas pipeline due to a 132 kV transmission line and the influence of variations in soil characteristics along the common utility route. The AC interference levels with respect to human safety and AC enhanced corrosion are discussed using the applicable industry safety standards.

Keywords: Electromagnetic Interference, AC Corrosion, Multilayer Soil, EMI, Metering Station, Valve Station, Coating Stress Voltage, Pipeline Touch Voltages.

INTRODUCTION

The continuous development of the HVAC transmission & distribution systems over the last few decades has resulted in an increase in common utility corridors where oil, gas & water pipelines are installed in proximity to overhead electrical power lines (OHL). Metallic pipelines that share these common corridors are subjected to electromagnetic interference (EMI) which can pose significant threats to pipeline operational maintenance personnel at exposed areas of the pipeline and its appurtenances. Furthermore, the electromagnetic interference resulting from exposure to the HVAC overhead electrical power lines can lead to accelerated corrosion of the metallic pipeline surface. Excessive induced AC currents cause metal loss as the induced currents discharged to the local soil through pipeline coating defects (holidays), i.e. AC corrosion, can be significant during normal sustained load conditions on the overhead electrical power lines.

The AC interference from the electrical power lines to the adjacent pipelines can be classified into three categories: inductive, conductive, and capacitive.

- Inductive interference is the dominant interference mechanism under normal electrical power line load conditions. Inductive interference occurs as AC current flowing along electrical power line conductors generates an electromagnetic field which induces an AC voltage on the adjacent metallic pipelines.
- Capacitive interference is primarily a concern during the pipeline's construction phase, where sections of the pipeline are electrically isolated from the earth as they sit above ground on insulated supports. The sections of pipeline can accumulate a significant electric charge acting as a capacitor, the surrounding air acting as the dielectric medium.
- Conductive interference is the dominant interference mechanism during fault conditions on the adjacent electrical system; the overhead electrical power lines tower earthing system allows large amounts of fault current to pass into the mass of earth. During a fault, AC interference on the pipeline typically includes all three; inductive, capacitive, and conductive components. It should be noted that inductive interference can also be a concern as the fault current passing through the intact phase conductors can generate significant levels of electromagnetic interference. The capacitive component is typically negligible compared to the inductive and conductive components.

In general, the level of AC interference depends on several factors including the physical separation between the electrical power lines and pipeline; the length of parallelism: the pipeline coating material; soil structure along the common utility corridor and the length of the common utility corridor. There are several technical publications which focus on the many issues that affect HVAC interference on metallic pipelines, calculation methods and proposed mitigation strategies [1-4].

Carrying out detailed analysis of the AC interference at a very early planning stage of the project is key for the design of a reliable and cost-effective mitigation solution. This requires extensive field measurements including soil resistivity measurements at regular intervals along the common utility corridor and resistance measurements of the overhead electrical power lines tower footer earthing systems. This detailed information is required to accurately represent the overhead electrical power lines, tower structures, substation earthing systems and pipeline or its appurtenances e.g. valve and test stations.

The safety recommendations for AC interference levels are set forth in the various national and international standards [5-9]. As outlined in the British Standard (BS EN 50443:2011[8]), under normal load conditions on the electrical power lines, the interference voltage (r.m.s. value) of the pipeline system versus earth or across the insulating joints at any point normally accessible to any (electrically) instructed persons shall not exceed 60 V. During fault conditions on the electrical power lines system, the interference voltage (r.m.s. value) of the pipeline system versus earth or across the insulating joints at any point normally accessible to (electrically) instructed persons shall not exceed the values detailed in Table 1.

Fault duration time (S)	Interference voltage r.m.s. value (V)
t ≤ 0,1	2,000
0,1< t ≤ 0,2	1,500
0,2 < t ≤ 0,35	1,000
0,35 < t ≤ 0,5	650
0,5< t ≤ 1,0	430
1< t ≤ 3	150
t > 3	60

Table 1: Limits for Interference Voltage Related to Danger to (Electrically) Instructed Persons

For pipeline safety, under normal operating conditions the interference voltage (r.m.s. value) between any point of the metallic pipeline system and the earth or the voltage between any element of the electric/electronic equipment connected to the metallic pipeline and the earth shall not exceed 60 V. For fault conditions, the interference voltage (r.m.s. value) between the metallic pipeline system and the earth at any point of the pipeline system, or the interference voltage (r.m.s. value) between any element of the electric/electronic equipment connected between the metallic pipeline and the earth, shall not exceed 2,000 V. The voltage difference (r.m.s. value) across an insulating joint shall not exceed 2,000 V.

It is generally agreed that the risk of AC corrosion is dependent on the AC current density and the soil conditions surrounding pipeline coating defects (holiday). In accordance with British Standard BS EN 15280:2013 [8], 15 V rms is considered to be an acceptable level of AC interference voltage, while 30 A/m^2 is considered an acceptable level of current leakage density. These values are measured as an average over a representative period of time, typically a continuous 24 hours. Where it is not possible to achieve these limits, effective AC corrosion mitigation can also be achieved by maintaining a ratio between a.c. current density ($J_{a.c.}$) and d.c. current density ($J_{d.c.}$) of less than 5 over a representative period of time.

Numerous calculation methodologies exist to assess the levels of AC interference but generally, the AC interference assessment studies uses simplified calculation methods. Such simplified calculation methods are based on empirical formula or on the assumptions that the soil structure is uniform throughout the corridor under study. As the soil structure can have a significant effect on the levels of AC interference the simplified calculation methods cannot accurately predict the levels of AC interference using a uniform soil model. This paper will assess the level of interference firstly using a uniform soil model. The level of AC interference will then be assessed using a multilayer soil model to determine the impact of soil structure representation.

COMPUTATION METHOD

The Hybrid Circuit and Conductive Based Computation Method uses both hybrid circuit theory and frequency-based grounding analysis to carry out detailed system designs involving complex right-of-way network configurations. It can accommodate various soil structure models and characteristics throughout the entire length of the corridor under study. It can rapidly model a corridor in which multiple energized and deenergized power line circuits and other utilities run in parallel to one another, at varying separation distances, for hundreds of miles (Right-Of-Way Pro [9]).

CASE STUDY

The case study assesses the AC interference levels on a 10” diameter buried Steel Gas Pipeline running in parallel with a 21 km long, 132 kV double circuit transmission line. Figure 1 shows a plan view of the common utility corridor under study. The transmission system is constructed of *AAAC* Upas phase wires and a single *ACSR* Horse earth/shield wire. The geometrical configuration of the transmission steel lattice tower is shown in the left of the figure below. The tower footer earthing systems were modelled using a value of 9.5 Ω per tower and transmission line was modelled with an average span length of 250 m. The steel pipeline has a coating leakage resistance of 20,000 Ωm^2 and is buried at a depth of 2.0 m. The pipeline converges with the 132 kV double circuit transmission line and shares the corridor with varying separation distance before finally diverging away from the 132 kV double circuit transmission line after

13.8 km. The common utility corridor also contains a gas valve station. The gas valve station earthing system consists of 40 mm x 4 mm copper tape, buried at a depth of 600 mm below ground and is shown in the right of the figure below.

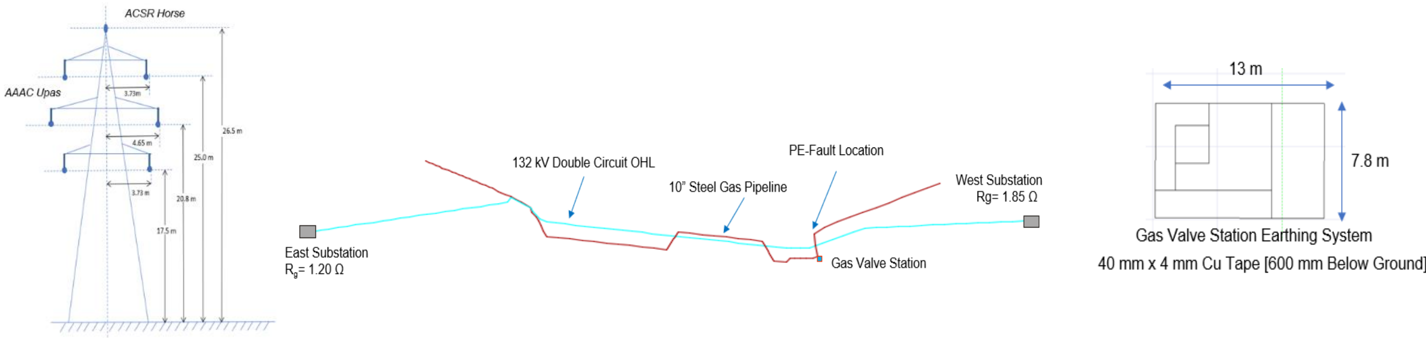


Figure 1: Common Right-of-Way Plan View and Gas Valve Station

RESULTS WITH UNIFORM SOIL

The AC interference levels were first assessed using a uniform soil of 112 Ω-m throughout the length of the common utility corridor. Normal load and fault conditions on the transmission line were simulated using the Hybrid Circuit and Conductive Based Method.

1. Steady State Condition

The steady state AC interference levels were assessed using an anticipated normal peak load current value of 310 A for the 132 kV double circuit transmission line. Two key parameters assessed during steady state conditions were, the pipeline metal GPR (ground potential rise) which is the GPR of the pipeline conductor calculated with respect to remote earth and the AC leakage current density through a 1 cm^2 coating defect (holiday). The key results for pipeline and its valve station are detailed in Table 2.

Pipeline Parameter	Maximum Value
Pipeline Metal GPR (V)	18.35
AC Leakage Current Density (A/m^2)	37.85
Potential at Valve Station	Maximum Value
Step Potential (V)	0.71
Touch Potential (V)	2.76

Table 2: Metal GPR & AC Leakage Current Density - Steady State Condition

Figure 2 shows the pipeline metal GPR (ground potential rise) and AC leakage current density through a 1 cm^2 coating defect (holiday). The figure shows higher potential at the start and ends of the pipeline. For more complex right of way configurations, the induced voltages can reach their maximum values at the pipeline crossing and at the locations where the pipeline veers away abruptly from the overhead electrical power lines or vice versa.

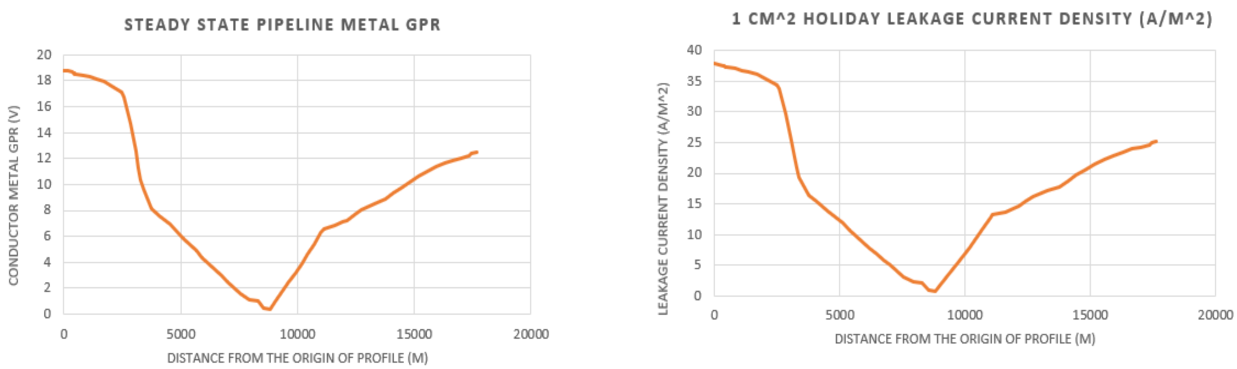


Figure 2: Pipeline Metal GPR & AC Leakage Current Density - Steady State Condition

2. Phase to Earth Fault Condition

With respect to Figure 1, a phase to earth fault was modelled on a single circuit phase C conductor near the gas valve station where the pipeline and transmission line intersect. The fault infeeds from Substation East and Substation West were 4,219.5∠98.85° A and 2,350∠103.77° A, respectively. Under phase to earth fault conditions on the 132 kV double circuit transmission line, the pipeline metal GPR (ground potential rise) and coating stress voltages were calculated. The key results for pipeline and its valve station are detailed in the Table 3.

Pipeline Parameter	Maximum Value
Pipeline Metal GPR (V)	1,200.42
Pipeline Coating Stress Voltages (V)	1,186.68
Potential at Valve Station	Maximum Value
Step Potential (V)	261.46
Touch Potential (V)	790.98

Table 3: Pipeline Metal GPR & Coating Stress Voltage - Phase to Earth Fault Condition

Figure 3 shows the pipeline metal GPR (ground potential rise) and coating stress voltages. The figure shows an induced potential peak in the pipeline voltages near the fault location. Where the pipeline crosses being perpendicular (90 degrees) to the electrical power line, negligible induction will occur, the pipeline interference voltage at these locations are caused by conductive component of AC interference.

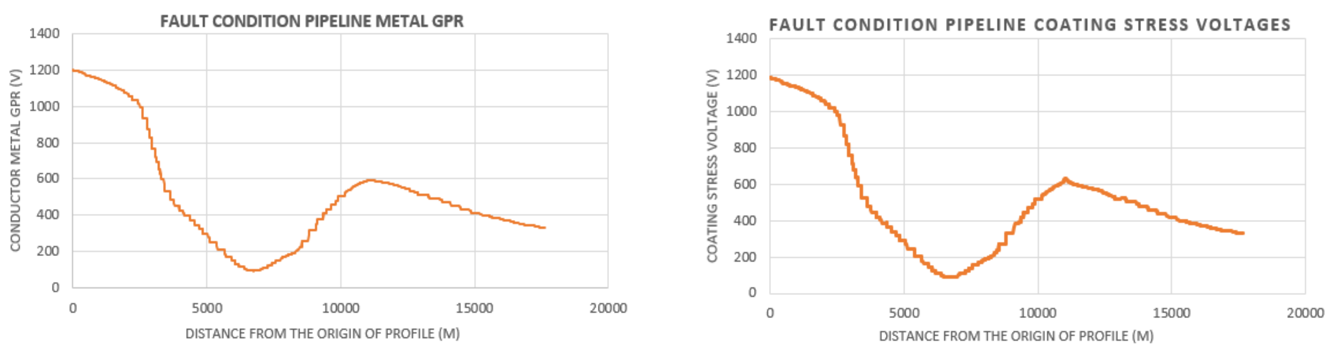


Figure 3: Pipeline Metal GPR & AC Leakage Current Density - Phase to Earth Fault Condition

RESULTS WITH MULTILAYER SOIL

The soil characteristics along the common utility corridor play a vital role in any AC interference study. The soil characteristics along the common utility corridor can be used to calculate the tower footing resistance of overhead electrical power lines, assess the pipeline mitigation wire performance and also to calculate realistic touch and step voltages at valve sites. The soil characteristics are also key to determining the conductive coupling of the pipeline through the earth from the nearby faulted overhead electrical power lines. Furthermore, the soil resistivity is important in the analysis of level of corrosion risk and the design of mitigation measures. Therefore, the analysis also considered multilayer soil models. Table 4 describes the six multilayer soil models that were used at different locations along the route.

Soil Model	Resistivity (Ωm)			Thickness (m)		
	Top Layer	Central Layer	Bottom Layer	Top Layer	Central Layer	Bottom Layer
1	251.6	980.8	1,288	1.5	2.5	∞
2	313.5	2,100	2,828.5	0.95	2.5	∞
3	1,750	810.6	2,650	1.4	4.8	∞
4	150.5	750	45.8	1.5	16.5	∞
5	613.5	50	350	4.9	5.5	∞
6	278.5	150	1,498.91	10.5	2.5	∞

Table 4: Multilayer Soil Models at Common Right-of-Way

1. Steady State Condition

Similar to the case of the uniform soil study, two key parameters, the pipeline metal GPR (ground potential rise) and the AC leakage current density through a 1 cm^2 coating defect (holiday) were assessed. The key results are detailed in Table 5. Figure 4 shows the pipeline metal GPR and AC leakage current density through a 1 cm^2 coating defect (holiday) for the length of the common utility corridor.

The analysis indicates that the overall pipeline potential increases as a result of high resistivity layers in most of the common utility corridor, as there will be stronger inductive coupling between the pipeline and the transmission line. A slight but visible difference was noticed for the calculated step & touch potentials at the gas valve station due to the presence of a multilayer soil structure. The soil resistivity shows a greater influence on the AC leakage current densities through coating defects (holiday). The high soil resistivity areas result in decreased AC leakage current density. Where the soil has lower resistivity, the holiday resistance 'R' will be much lower compared to high resistivity case. Consequently, the AC leakage current density through the coating defect (holiday) will be very high. It is noticed that the current density varies with induced voltage and heavily depends on soil characteristics along the common utility route.

Pipeline Parameter	Maximum Value
Pipeline Metal GPR (V)	28.02
AC Leakage Current Density (A/m^2)	15.61
Potential at Valve Station	**Maximum Value**
Step Potential (V)	1.02
Touch Potential (V)	3.02

Table 5: Pipeline Metal GPR & AC Leakage Current Density - Steady State Condition

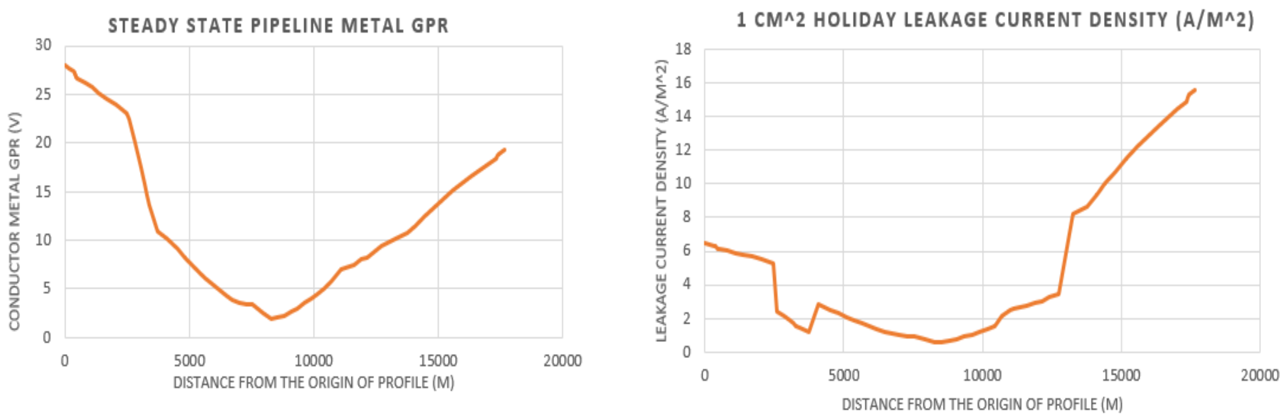


Figure 4: Pipeline Metal GPR & AC Leakage Current Density - Steady State Condition

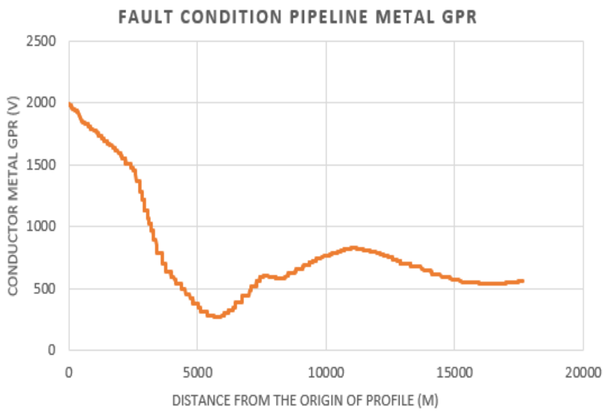
2. Phase to Earth Fault Condition

Similar to the case of the uniform soil study, the pipeline metal GPR (ground potential rise) and coating stress voltages were calculated. The key results for the pipeline and its valve station are detailed in the Table 6. Figure 5 shows pipeline metal GPR and coating stress voltages.

Similar to the case with a uniform soil model an induced potential peak in the pipeline voltages near the fault location was noted. The earth surface potentials near the pipeline will increase due to the presence of the high resistivity multilayer soil in most of the common utility corridor. As a result, the potential difference between the pipeline and the earth surface is significantly higher when compared to the case of a uniform soil. A significant difference was also noticed for calculated step & touch potentials at the gas valve station due to the presence of a multilayer soil structure.

Pipeline Parameter	Maximum Value
Pipeline Metal GPR (V)	1,991.46
Pipeline Coating Stress Voltages (V)	1,927.79
Potential at Valve Station	Maximum Value
Step Potential (V)	201.77
Touch Potential (V)	612.0

Table 6: Pipeline Metal GPR & Coating Stress Voltage - Phase to Earth Condition



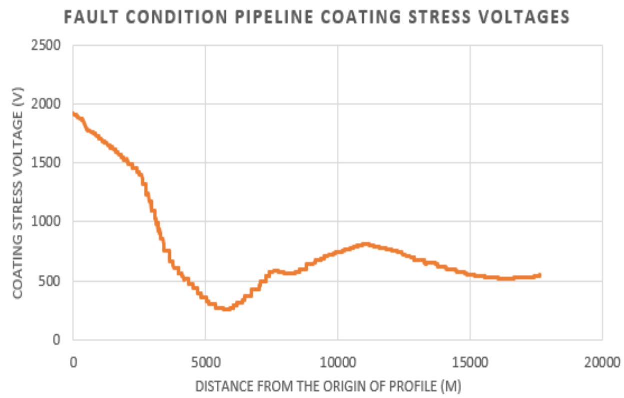


Figure 5: Pipeline Metal GPR & Coating Stress Voltage- Phase to Earth Condition

CONCLUSION

A typical study of AC interference on a metallic pipeline caused by overhead electrical transmission line has been carried out. The analysis shows that the uniform soil approach cannot be used to accurately assess the AC interference effects on exposed metallic pipelines. Further, it was noted that the magnitude of pipeline potentials and excessive AC leakage current densities through the coating defects are greatly affected by soil resistivity along the common utility corridor. The analysis indicates that the pipeline potential increases in areas of high soil resistivity, while the AC leakage current density decreases. This case study shows how modern computational approaches can be used to accurately analyze complex AC interference problems.

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