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EM Interference on 24” Subsea Pipeline Due To Piggybacking of 33kv Cable

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***Abstract* - EM Interference due to a transmission line or cable having common right of way with a metallic utility can cause serious damage to the utility structure or the public in close vicinity. This paper describes a similar case study where EM effects are studied due to a 33kV subsea cable sharing common right of way with a 24” subsea pipeline. The study has been performed to analyze the typical hazards on pipeline integrity as well as human safety. CDEGS software has been utilized for the study and necessary mitigation measures have been worked out.**

Keywords—EM Interference, AC Interference, Inductive coupling, Resistive Coupling, Multilayer soil modelling, Coating Stress Voltage, AC leakage current density, NACE SP0177, Mitigation Design, Lumped Grounding Method.

I. INTRODUCTION

A neighboring utility such as oil, gas, or a water pipeline, irrespective of its installation i.e., onshore, offshore, buried or above the ground, if shares common right of way with an AC overhead transmission line or a buried cable in close proximity, can develop induced potentials due to the electric and magnetic fields of the current flowing through the cable. These induced potentials can cause serious hazard to the integrity of pipeline or can result in serious shock danger to the people working on it or standing nearby.

The purpose of this paper is to describe a case study performed to identify the hazards due to a 33 kV onshore-offshore cable sharing common right of way with a 24” subsea pipeline and piggybacking on the pipeline for a distance of. 5 kms. EM interference effects i.e., induced voltage (GPR of pipeline), AC corrosion currents, dangerous touch voltages, coating stress voltage have been computed and compared with the permissible values provided in international standards i.e., NACE SP 0177, NACE 21424, IEEE 80. Accordingly, mitigation strategies have been discussed with results to show the effect of mitigation strategy implemented. For the analysis and the mitigation design, the author has utilized SES CDEGS software.

II. INTERFERENCE MECHANISM

The electromagnetic interference mechanism between an energized conductor and neighboring utility such as pipeline, fence, rail etc. at low frequency can be divided into three typical categories – inductive, conductive, and capacitive.

A. *Inductive Coupling*

Inductive coupling is the effect when a conductor induces a longitudinal flow of electric current due to an AC energized conductor passing nearby. The magnitude of this induced current depends majorly on the magnitude of the energized line, separation distance of that line and length of parallelism.

B. *Conductive Coupling*

Conductive coupling is the effect when a conductor (e.g., a tower, gantry, grounding system) being grounded, dissipates the current into the earth (during a line to ground fault or lightning strike). This raises the soil potential around the conductor faulted conductor. Consequently, any nearby pipeline, fence or other metallic conductor/victim which is earthed in that soil may collect the soil potential and may have high GPR (ground potential rise). The magnitude of conductive coupling decreases when the distance from the dissipating conductor increases. The magnitude of conductive coupling also strongly depends on electrical resistivity of the soil medium.

C. *Capacitive Coupling*

Capacitive coupling can occur between an energized conductor and any freely suspended or earthed conductor paralleling at significant separation distance e.g., an overhead transmission line have parallelism with an overhead water pipeline. This is due to the displacement current flowing through the air to the conductor and if it is grounded, then to the soil. The magnitude of total current flow from the energized structure depends on the size of victim/affected conductor, separation distance, the voltage level of energized conductor and their geometrical arrangement. However, this effect is very negligible as compared to inductive coupling.

III. SYSTEM DESCRIPTION

The system consists of a 33kV cable and a 24” pipeline sharing common right of way for a length of 40 kms. For first 6 kms, 33kV cable and 24” pipeline is separated at a distance of 5 meters and buried directly in Onshore soil. Rest, 34 kms of the

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cable and pipeline are in Offshore soil/seawater. The entire length of pipeline has been considered buried at a depth of 1.5 m.

33kV cable is piggybacking on 24" pipeline for a distance of 5 kms from the seashore as shown below. After 5 kms, 33kV cable is separated at a distance of 15 meter as shown in

Figure 1 below.

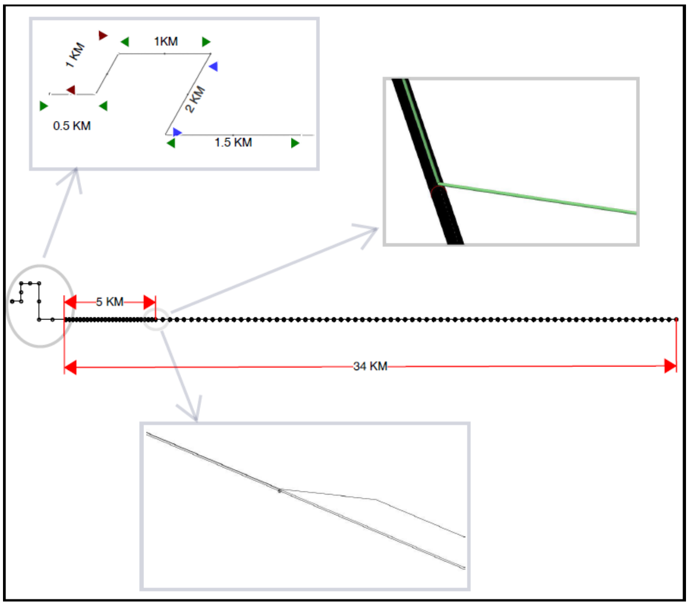

Figure 1 - 3D Model of 33kV & 24" Pipeline System

Inputs considered for the case study are given below –

A. Soil Resistivity Data

Soil model considered for the analysis has been given below –

1. Onshore Soil Resistivity

Soil Layer	**Soil Resistivity (Ohm-m)**	**Thickness (in meters)**
Top	10	5
Bottom	0.1	Infinite

2. Offshore Soil Resistivity – Representing the sea water electrical resistivity.

Soil Layer	**Soil Resistivity (Ohm-m)**	**Thickness (in meters)**
Top	1	Infinite

B. 24" Pipeline Data

Following inputs have been considered for the 24-inch carbon steel pipeline –

- 24" carbon steel pipe with pipe wall thickness of 9.525 mm. FBE coating implemented on pipe metal with a coating resistance of 20000 Ohm-m^2 for a thickness of 0.66 mm.
- The pipeline has been considered buried at a depth of 1.5 m throughout the corridor.
- 8 nos. of anode bed with equivalent resistance of 0.07 has been modelled on Onshore section of pipeline (first 6kms) at different locations.
- The existing system consists of sacrificial anode bracelet on the offshore section of pipeline at every 200 meters from the seashore point of the pipeline. Every 200 m a sacrificial anode bracelet has been modelled up to 5 kms. However, for simplicity of network, anode bracelets, after the piggyback end have been modelled at 400 meters.
- Pipeline has been considered grounded at Offshore end with resistance equivalent to 0.12 Ohms. However, at starting of pipeline at Onshore side, it is terminated using insulating joint.
- Onshore (first 6 kms) and Offshore (34 kms) portion of pipeline has been connected using insulating joint at shoreline.

C. 33kV Cable Data

Following inputs have been considered for the 33 kV Cable –

- It is a 3Cx185 sq. mm. subsea cable where sheath and armor have been grounded at both ends.
- Cable loading details are as follows –

Peak Load Current	400 Amps
LG Fault	2.3 kA
LLL Fault	4.3 kA

The objective of the study is to analyze safety concerns under both steady state as well as fault conditions. The parameters like pipe touch voltage at exposed facilities served by the pipeline, coating stress voltages, AC corrosion current in A/m^2 have been analyzed to meet with the permissible limits specified in international standards e.g., NACE and IEEE standards.

IV. STUDY CRITERIA

The dangerous effects of EM interference cause the typical issues like dangerous touch potentials at the exposed utilities of the pipeline, high coating stress potentials and enhanced AC corrosion through the pipeline coating defects. International standard committees have set the criteria to safe limit these three parameters of the pipeline. Following criteria has been set for a typical EM Interference study –

A. Touch and Step Potential Limits

The safety of the operator or any human being in contact with the pipeline is a major concern due to the high potential rise caused by EM interference. Touch potential is defined as the potential difference between the exposed area of the pipeline such as valve and the surrounding soil. While step potential is the potential developed across the two feet of a human being at 1 meter as the stride of a person. It is the surface potential difference of the soil between two points at 1 meter apart.

Touch potential is of significant concern during normal operation as well as during faulted conditions of the system whereas step potential is of concern during a conductive fault condition as the soil potential rises resulting in high voltage gradients in the soil.

NACE (National Association of Corrosion Engineers) Standard Practice SP0177-2014, Mitigation of Alternating Current and Lightning effects on Metallic Structures and Corrosion Control Systems, has define a normal condition touch and step potential of **15 V** with respect to remote earth at above ground or exposed sections and appurtenances to constitute a shock hazard.

Whereas for fault condition, a permissible value of maximum touch potential can be computed by using the IEEE 80 standard - Guide for safety in AC substation grounding.

B. *Coating Stress Voltage*

During a Line to Ground fault, the pipeline may get subjected to both inductive and conductive interference. However, conductive interference being dominating, the pipeline may have high potential around it as the Line to Ground fault current is injected in the soil medium depending on the separation distance between the power line or cable. Though these faults are normally of short duration (< 1 sec). The pipeline could have a coating breakdown caused due to the potential stress from surrounding medium (soil or sea water).

As the line to ground fault current is typically carried by a single conductor, the short term induced voltage could reach the order of 1 kV or more on a case-to-case basis. This may be very dangerous for any person in contact with the pipeline or any electrically continuous appurtenance.

The main factor is the voltage gradient and dielectric strength of the coating on the pipeline causing the coating damage. NACE SP0177 has set following coating stress voltage limits for short duration faults based on different type of coatings –

- Bitumen: 1 – 1.2 kV
- Coal Tar: 3 kV
- Asphalt: 3 kV
- Fusion Bonded Epoxy (FBE): 3- 5 kV

C. *AC Corrosion Current*

The current induced in the pipeline due to EM interference can have serious hazard of accelerated corrosion on the pipeline through the probable coating damages on the pipeline occurring during transportation and handling. The integrity of pipeline is threatened by AC corrosion during its service life. Pipelines are generally protected by cathodic protection systems either sacrificial type or Impressed Current Cathodic Protection (ICCP) to provide electrochemical protection at coating holidays to reduce the corrosion rate of pipeline. However, AC corrosion is still possible due to high AC current density at coating holidays.

As per NACE International report of January 2010 titled AC Corrosion State of the Art: Corrosion Rate, Mechanism and Mitigation Requirements, the following conclusion had been made –

- AC-induced corrosion does not occur at AC densities less than 20A/m^2.
- AC corrosion is unpredictable for AC densities between 20 to 100A/m^2.
- AC corrosion occurs at current densities greater than 100A/m^2.

AC current density of the pipeline depends upon the soil resistivity, induced voltage and size of the holiday/defect in the coating. However, research indicates that the highest corrosion occurs at the holidays with surface areas between 1 – 3 cm^2.

As per NACE SP21424-2018: Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring, the AC current density limit has been adopted to 30 A/m^2 as the lower threshold below which AC corrosion is unlikely.

V. SIMULATION METHOD

CDEGS (Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis) Software is a power software integrated with set of tools designed to analyze different electromagnetic related problems which are encountered in most of the industries involving electric networks.

Electromagnetic Field Theory has been used in software to analyze the complex problem of electromagnetic interference. The system has been modelled in software including the pipeline and cable piggybacking and getting separated at the distance specified in the inputs. Soil medium to represent Onshore soil and Offshore seawater medium has been assigned the computed electrical resistivities. Parameters to be analyzed have been computed and plotted. Wherever required mitigation has been modelled and results have been plotted to see if the mitigation strategy is really effective to reduce the EM interference levels within the permissible limits.

VI. NORMAL LOADING CONDITION OF 33KV CABLE

It is to be noted that AC corrosion is the only point of concern during normal operation of cable. As for a short circuit scenario, the duration of fault is so small that it will not have any significant impact on pipeline in reference to accelerated corrosion. However, during fault scenario, coating stress voltage and touch voltages can be dangerous to pipe or personal in contact with it. Same has been analyzed in next sections.

Under normal loading condition of the cable, as stated the inductive coupling is dominant factor and plays the role in inducing the potentials on the pipeline. The current flowing in each phase is low in the magnitude (400 A). However, even this much current can be enough for accelerated AC corrosion in pipeline due to induced AC currents. Same has been studied in this scenario.

System has been modelled in SESCAD tool used for 3D modelling of arbitrary system. Below

Figure 2 shows the system modelled in SESCAD for further analysis.

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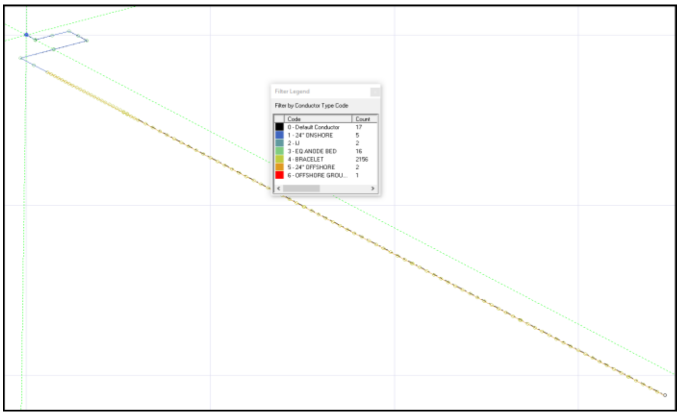

Figure 2 – 33kV cable and 24'' pipeline system

From the analysis, results have been plotted for onshore and offshore sections of the pipeline as shown in *Figure 3* ***to***
Figure 6 below.

Figure 3 - Cable Current of 400A in all 3 cores

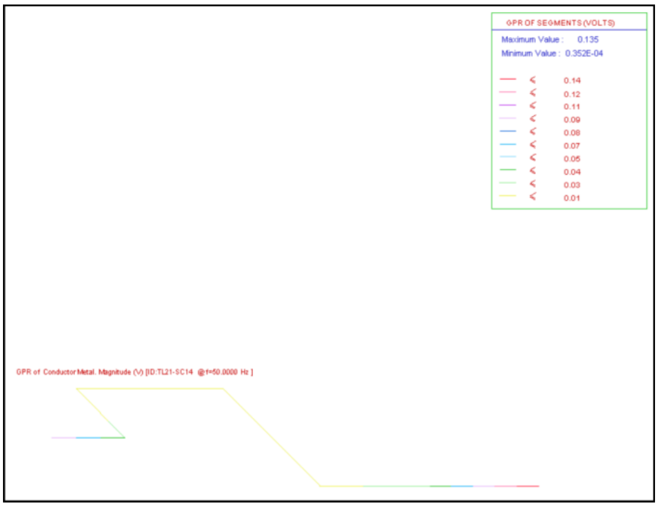

Figure 4 – Induced Voltage (GPR) in Onshore Section of Pipeline

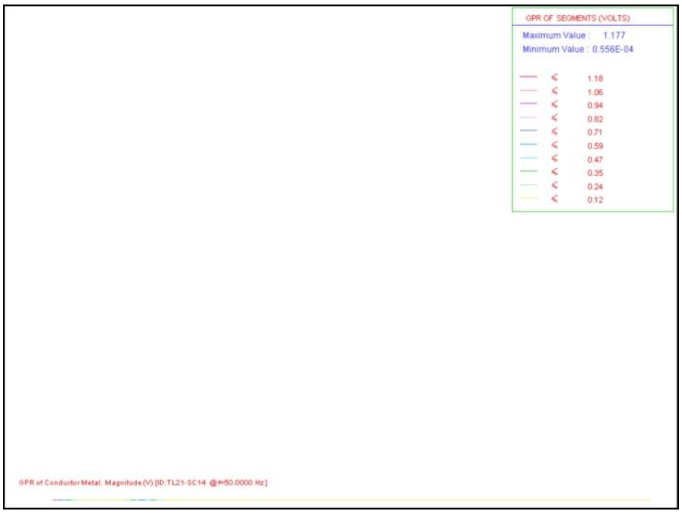

Figure 5 – Induced Voltage (GPR) in Offshore Section of Pipeline

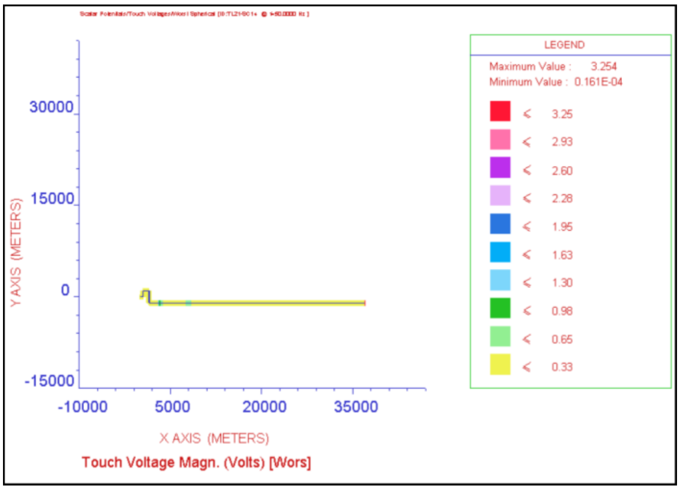

Figure 6 - Max. Touch Voltage at Pipeline Appurtenance

Following table & graph shows the results obtained for normal operating conditions of the cable –

Onshore Section Induced Voltage (volts)	Offshore Section Induced Voltage (volts)	Max. Touch Voltage (volts)
0.135	1.177	3.254

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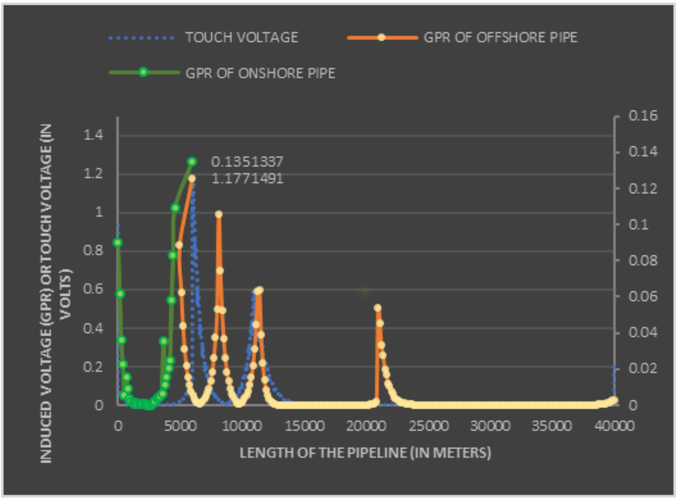


NOTE – Blue and orange trend is not continuous in the plot as Onshore and Offshore sections are separated by insulating joint.

From the results, it is identified that the cable peak loading current of 400 amps is significant to induce the GPR of 1.177 volts in the offshore section of pipeline. This induced EMF is significant enough to cause accelerated AC corrosion currents on the pipeline. The calculation of this AC corrosion currents leaving the pipeline from a 1 cm^2 holiday are based on below formula –

$$I_{AC} = \frac{225 V_{AC}}{\rho}$$

Where,

I_{AC} = Theoretical AC Current Density in A/m2

V_{AC} = Pipe AC Voltage to Remote Earth (V)

ρ = Soil Resistivity (ohm-m)

Computed AC leakage current density through 1 cm^2 holiday (A/m^2)	Permissible AC leakage current density through 1 cm^2 holiday as per NACE (A/m^2)
264.8	20

AC current leaking through 1 cm^2 coating holiday has been calculated as **264.8 A/m^2**. As per NACE criteria, this AC leakage current is significant enough to cause accelerated corrosion on pipeline. Whereas pipe touch voltage and step voltages at the appurtenance are none of a concern as the GPR due to induced potentials on the pipeline itself is 1.2 volts. This pipeline GPR of 1.2 volts is well within the permissible limit of 15V during normal operating conditions.

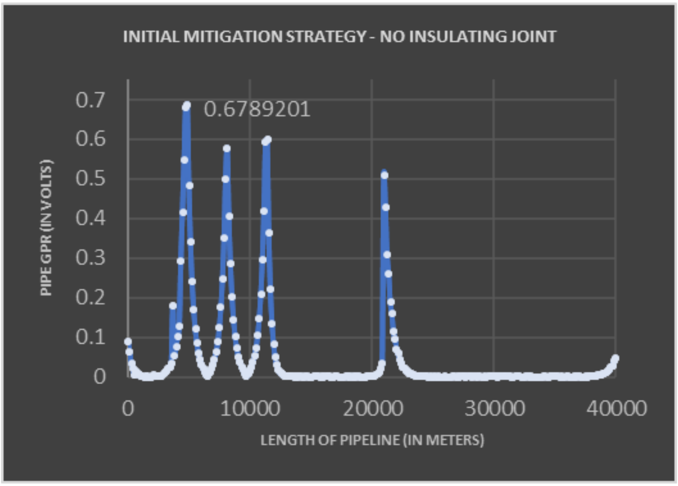
To ensure the AC leakage currents are within the permissible limits, a mitigation strategy shall be analyzed and implemented for safe operation of pipeline. Same has been discussed in the next section.

VII. MITIGATION STRATEGY

For the purpose of mitigating the AC interference problem, before proposing any additional measure, a common remedy has been analyzed. As the initial design of the pipeline has been proposed with an insulating joint at the shoreline (between onshore and offshore sections). It is observed that removing the insulating joint and keeping the pipeline continuous may help to lower the induced potentials on the pipeline.

Initial Mitigation Strategy – Removing Insulating Joint Between Onshore and Offshore Section – case has been studied where the insulating joint has been removed and pipeline has been kept continuous. Below table compares the two cases where insulating joint has been considered as per the existing design and mitigation strategy where insulating joint has been removed. Below table gives the calculated results –

Max. Pipe GPR with Insulating Joint between Onshore and Offshore section of pipeline	Max. Pipe GPR without Insulating Joint between Onshore and Offshore section of pipeline
1.177	0.688



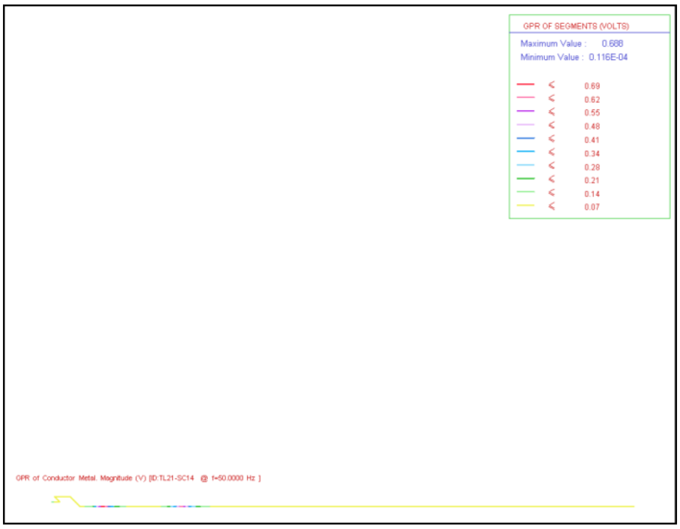


Figure 7 – Induced Voltage (GPR) in Pipeline after Removing Insulating Joint

From ***Figure 7*** above, it is observed that after removing insulating joint the overall induced voltage (GPR) has been distributed which lowers the overall GPR value on the pipeline from max. 1.177 volts to 0.68 volts. The GPR of 0.68 volts is seen on the offshore buried pipeline. This GPR value is still higher when analyzed from the corrosion point of view as the AC corrosion current density calculated through a 1 cm^2 holiday equal to **154.8** A/m^2 which is still much higher than the permissible value as per NACE standard. Hence, this strategy has not been analyzed further.

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Under normal loading condition of 33kV cable, it has been observed that the induced potentials in the pipeline are significant enough to cause accelerated AC corrosion. However, touch potentials are seen to be well within the permissible limits of 15V.

The induced voltage on the pipeline shall be reduced in order to avoid the accelerated corrosion of the pipeline during normal operation of cable. There are various mitigation strategies discussed in NACE SP 0177 standard e.g., lumped grounding, gradient control wires and mats, distributed anodes and cancellation wire method.

Even after inclusion of anode bracelets existing in the design at every 200 m to protect the pipeline from galvanic corrosion. The AC corrosion effect has been identified due to induced potential. Another mitigation strategy has been considered as described below during normal operation of cable.

Mitigation by Lumped Grounding Method - Lumped grounding method has been analyzed below to mitigate the accelerated AC corrosion currents by reducing the pipeline GPR. In this method, localized conductor or conductors shall be connected to the affected structure at strategic locations (where GPR is high compared to other areas of structure). It is intended to protect the structure from steady state as well as faulted AC conditions. This system can be installed in shallow or deep configurations, depending on site specific parameters.

A conductor mat has been designed which consists of 30x30 m mesh with 10 nos. of horizontally and vertically connected conductor (separation of 3m). This mat has been connected to the pipeline at the shoreline side of the offshore pipeline (point where piggybacking starts) and at 5 kms from starting of piggyback, where cable is separating from the pipeline. The connection between the mat and pipeline can be made using an insulated cable. The earth mat has been computed for earth resistance using IEEE 80- and 0.01-Ohm resistance has been calculated. ***Figure 8*** below shows the design of the earth mat.

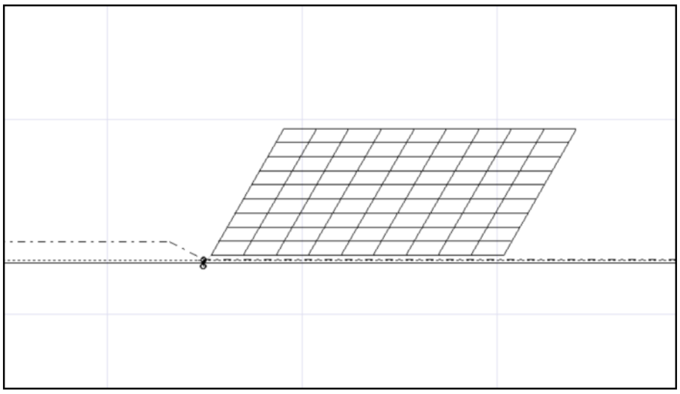

Figure 8 - 30x30 m Mitigation Mat connected to Pipeline

Above detailed mitigation system has been analyzed. Below are the results from the analysis after implementing the mitigation strategy.

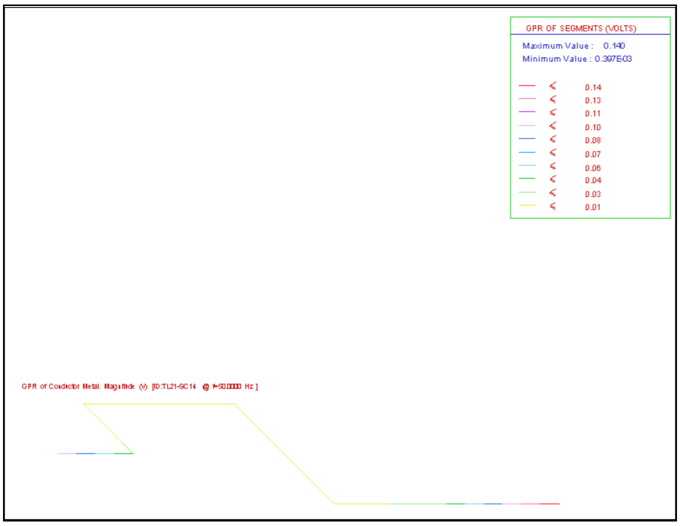

Figure 9 – Induced Voltage (GPR) in Onshore Section of Pipeline

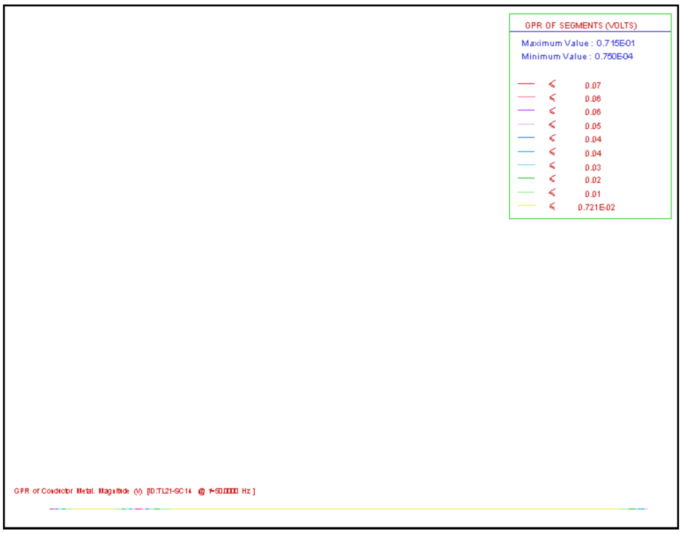

Figure 10 - Induced Voltage (GPR) in Offshore section of Pipeline

Figure 9 & ***Figure 10*** show the induced potential in the Onshore and Offshore sections of the pipeline, respectively when 33 kV cable is carrying the maximum normal operating current of 400 Amps.

Following table & graph provides the computed results from above plots –

Onshore Section Induced Voltage (volts)	Offshore Section Induced Voltage (volts)	Max. Touch Voltage (volts)
0.140	0.068	1.173

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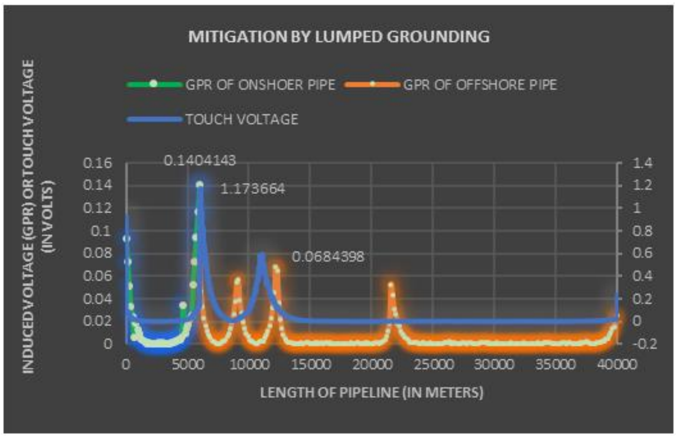

It can be observed that induced potential in the pipeline after implementation of the mitigation strategy, has decreased drastically **0.07** volts as the pipeline has been grounded and the induced potentials have been transferred into the ground. The earth mat connected to the pipeline also helps to increase the local potentials around the pipe resulting in lower touch potentials and coating stress voltages in case of a fault.

Furthermore, after the calculation of AC corrosion current through the 1 cm^2 holiday defect, the AC corrosion current density of **15.75 A/m^2** has been computed. It is well within the permissible limit as specified in NACE standard and concludes that there is no harm to pipeline due to the effects EM interference.

VIII. FAULT CONDITION STUDY WITH MITIGATION DESIGN

As mentioned earlier, it is to be noted that AC corrosion is the only point of concern during normal operation of cable. As for a short circuit scenario, the duration of fault is so small that it will not have any significant impact on pipeline in reference to accelerated corrosion. However, during fault scenario, coating stress voltage and touch voltages can be dangerous to pipe or personal in contact with it. Same has been analyzed in this section.

The mitigation design has been further studied for fault condition where Line to Ground and 3 Phase fault has been performed at the end of 33kV cable piggybacking the 24" pipeline. Line to Ground fault has been simulated by shorting the cable core 1 with sheath 1 while the fault current is 2.3 kA in the cable core. Similarly, 3 Phase fault has been simulated by shorting the 3 cores at the end of piggyback of 33kV while the fault current is 4.3 kA in the cable cores.

In compliance with IEEE80-2013 Standard, SESThreshold tool of SES Software has been utilized for the calculation of tolerable touch and step voltages. The tolerable values of step and touch voltages have been computed taking into account the two different soil resistivities, Onshore 10 Ohm-m and Offshore 1 Ohm-m. Based on 10 Ohm-m soil resistivity, the tolerable value of touch voltage of **252.2** volts has been computed. The calculated touch voltage at the pipeline appurtenance shall not exceed this value.

LG Fault – Below results have been obtained from the Line to Ground Fault study case performed during the analysis.

Figure 11 - LG Fault Current in Cable Core 1 & Sheath 1 Component

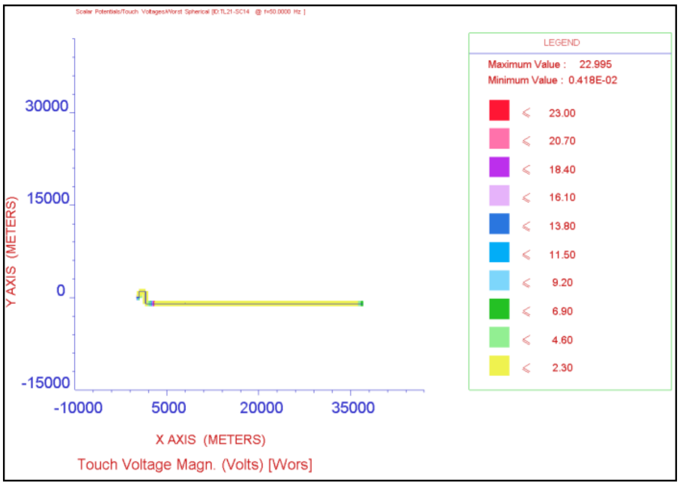

Figure 12 – Max. Touch Voltage at Pipeline Appurtenance

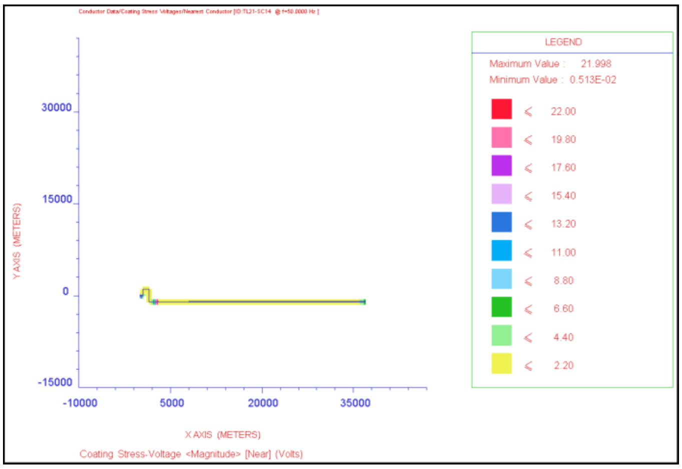

Figure 123 - Coating Stress Voltage on the Pipeline during LG Fault on 33 kV Cable

Following table provides the results obtained from the above case for LG fault scenario compared with the permissible limit as per NACE & IEEE 80 –

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	Computed Value	Permissible Value
Coating Stress Voltage (volts)	21.998	3000
Max. Touch Voltage (volts)	22.995	252.2

LLL Fault – Below results have been obtained from the 3 Phase fault study case performed during the analysis.

Figure 14 - LLL Fault Current in Cable Core 1 & Sheath 1 Component

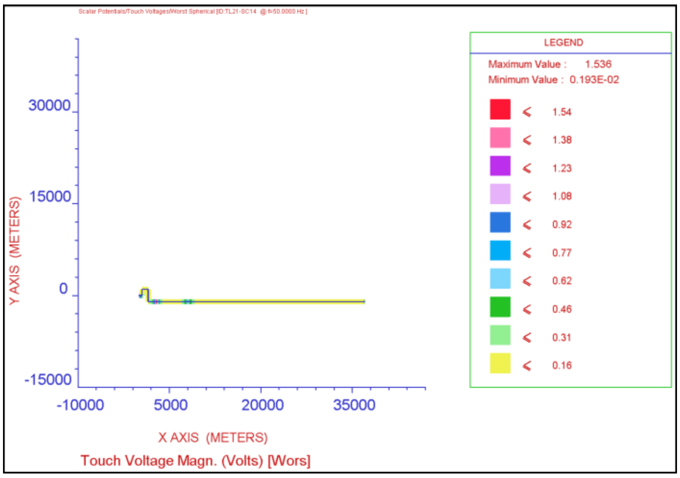

Figure 15 - Induced Voltage (GPR) in Offshore Section of Pipeline

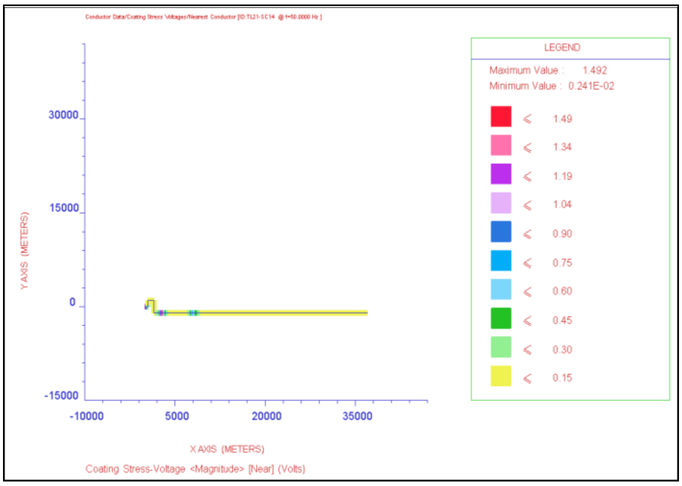

Figure 16 - Coating Stress Voltage on the Pipeline during LG Fault on 33 kV Cable

Following table provides the results obtained from the above plots for LLL fault scenario –

	Computed Value	Permissible Value
Coating Stress Voltage (volts)	1.492	3000
Max. Touch Voltage (volts)	1.536	252.2

From the result, it has been identified that the touch potentials and coating stress voltage are well within the permissible limits during the short circuit scenario. Hence, we can conclude that the proposed mitigation (Refer VII) helps lower the induced potentials on the pipeline which in turn reduces the AC leakage current density on the pipeline without posing any risk to coating or human safety during fault conditions.

IX. CONCLUSION

An electromagnetic study has been carried out for a case study where a common right of way has been shared by 33kV cable and a 24” pipeline including a section of 5 kms where 33kV cable is piggybacking on the 24” pipeline. Induced potentials on the pipeline have been calculated during steady state condition. While it has been identified that the pipeline poses the risk of accelerated corrosion due to EM effects of current flowing in the 33kV cable. A mitigation strategy has been studied (Refer VII). The mitigation measure proposed in the study has been concluded to be effective in reducing the pipeline potentials to the safe levels and avoid the accelerated corrosion to the pipeline. Similarly, to ensure that after mitigation, during short circuit condition there should be no damage to the pipeline coating or any touch voltage hazard should not exist. Cases have been performed for max LG and LLL fault conditions. The results for fault scenario have also been found well within the permissible limits. This case study shows how a mitigation design can be analyzed and a complex problem can be solved using the modern computational software i.e., CDEGS.

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