ENGINEER - Vol. LVI, No. 04, pp. [37-45], 2023

https://doi.org/10.4038/engineer.v56i4.7620

Voltage Impact on Oil Pipelines from High Voltage Underground Cables: Relocation of Overhead Lines at Kelanitissa

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Abstract: When a large-scale urban construction project requires the relocation of an electrical overhead transmission line, going underground becomes the only feasible solution. However, due consideration must be given to the interaction with underground steel pipelines already laid as the life of metallic pipelines is highly susceptible to corrosion when buried underground. Corrosion occurs because of an electrochemical reaction, with Impressed Current Cathodic protection, with an impressed negative dc voltage of the order of 850 mV, usually employed in many metal pipelines to mitigate the deterioration of the surface. This paper scrutinizes the impact of high voltage underground cables on the cathodic protection of buried metal pipelines. The induced voltage due to the addition of high voltage underground cables crossing the pipelines perpendicularly has been analysed using Ansys Maxwell's electromagnetic software using actual dimensions and parameters. The introduction of two 220 kV underground cables from Biyagama - Kelanitissa line and two 132 kV underground cable circuits from Kelanitissa - Kolonnawa running perpendicular to six underground petroleum carrying steel pipelines has been investigated to study its influence on existing impressed current cathodic protection. The study has shown that the maximum induced voltage is less than 1.5 mV which has no adverse effect on any existing impressed current cathodic protection. The high voltage cables have been in fact installed and no adverse effects have been detected.

Keywords: Underground cable, Electrical power line, Oil pipeline, Cathodic protection

1. Introduction

With growing urbanisation, power transmission through major cities needs to go underground [1]. Corridors for the underground cables, free of encumbrances, are usually absent. Many practical issues arise during installation of a new underground high voltage cable system due to the presence of steel pipelines for water, sewerage, gas, and oil [2], [3]. During installation of new underground cable systems, the cable routes may run across or in parallel with steel pipelines. Depending on the proximity to the pipelines and bonding arrangement of the cable system, the high voltage cables may induce a voltage on the steel pipelines [4]. When the pipeline is petroleum, excessive induced voltages can have drastic consequences [5]. Steel pipelines have the minimal induced voltage when the high voltage cables cross the steel pipes perpendicularly rather than running parallel [6]. However, steel pipelines are highly susceptible to corrosion when buried underground. Passive cathodic protection is usually insufficient to mitigate corrosion and increase the life of the steel pipes.

Thus, Impressed Current Cathodic (ICC)protection is usually employed to control the deterioration of the surface. This is the case with the petroleum pipelines, where a voltage below -850 mV is considered efficient [7]. This research paper presents the analysis of the impact of underground high voltage cables on the existing cathodic protection of metal petroleum pipelines when they cross perpendicular to each other. Construction of the new Kelanitissa Bridge [8] required the relocation of the overhead power transmission lines by an underground section.

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2. Relocation of Overhead Lines with Underground Cables

The scenario considered is the overhead transmission lines requiring relocation - two circuits of the 220 kV Biyagama - Kelanitissa line and two circuits of the 132 kV Kelanitissa - Kolonnawa line running near six underground petroleum carrying steel pipelines. Each high voltage (HV) cable resides inside a high-density polyethylene (HDPE) pipe arranged in trefoil form. To determine the distance between the pipeline and the HV cables, two key parameters were considered. Bending capability of the Horizontal Drilling facility was used since the open cut of the adjacent flood bund was restricted by the Irrigation Department, which influenced the minimum depth achievable at the point with the curve route. The maximum depth was limited by the derating factor of the power cables. Taking both into account, the most practical depth was chosen, and the case study was conducted for that depth. The worst-case scenario is analysed based on 220 kV cables with the parameters given in Table 1.

Table 1 - Parameters of Underground Cable Assembly and Steel Pipeline

Nominal diameter of copper conductor	45.8 mm
XLPE Insulation Thickness	21.3 mm
Aluminium Sheath Thickness	5.8 mm
HDPE Outer Jacket Thickness	5 mm
Outer diameter of HDPE pipe	250mm
Thickness of HDPE pipe	12mm
Arrangement of Pipes	Trefoil
Steel Pipe outer diameter	600 mm
Steel Pipe thickness	12 mm
Minimum vertical distance from cables to steel pipe	3 m
Bonding arrangement of underground cables	Single point bonding

2.1 Corrosion Protection of Buried Steel Pipes

Corrosion is a major problem for metal pipelines. In the case of uniform corrosion, a multitude of microscopic anodic and cathodic sites exist on the surface of the metal structure [8] as seen in Figure 1.ICC protection, usually employed in many metal pipelines, shown in Figure 2, is achieved by connecting the protected structure to an anode bed through a dc source, which forces the current to flow from the anodes to the protected structure which is acting as the cathode [10-12].

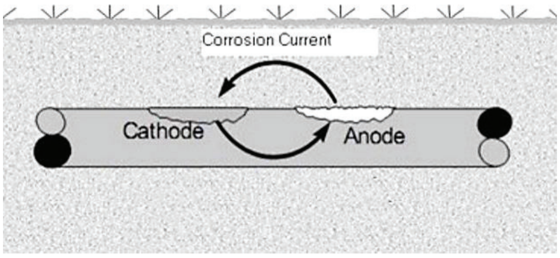

Figure 1 - Microscopic Corrosion Cell on the Surface of a Metal Pipeline [9]

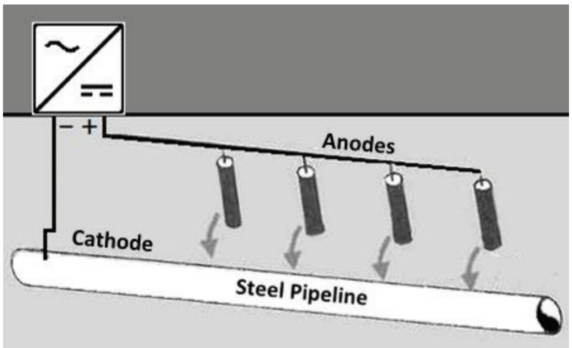

Figure 2 - Impressed Current Cathodic Protection

The anode bed is a series of buried anodes that are electrically connected and surrounded by certain backfill to reduce their resistance to the earth.

3. Simulation Model

Figure 3 shows the configuration of burial of an oil pipe and 220kV trefoil cable.

The parameters [13] shown in Table 2 were used in the initial simulation in Ansys Maxwell software [14], Electromagnetics suit. The top phase of the trefoil was considered to be at peak AC voltage and other two phases as half negative peak voltage at the simulated instant.

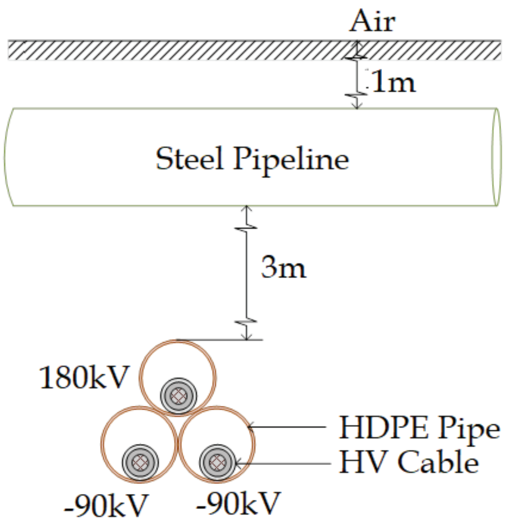

Figure 3 - Configuration of Burial of Oil Pipe and 220 kV Trefoil Cable

The maximum positive voltage on the topmost cable and corresponding values on the others are considered as a worst-case scenario inducing the highest possible voltage on the steel pipe. Air-soil interface was set at 1 m above the steel pipe. The height of the soil layer below the cable trefoil and the height of the air layer above is minimum 1 m in the simulated region. The voltage of the top-most soil level is set to 0 V. The simulation settings applied are also given in Table 2.

Table 2 -Parameters used in Initial Simulation

Top-most cable voltage	180 kV
Bottom two cable voltage	-90 kV
Cable/Pipe length	5m
Type of Bonding	Single point bonding
Centre of the trefoil	0V
Soil relative permittivity	10
Soil electrical conductivity	0.01S/m
Allowed percentage error	1%
Minimum number of converged passes	1 – 7

Figure 4 shows the initial configuration of the cable and pipeline used in the Ansys Maxwell software simulation.

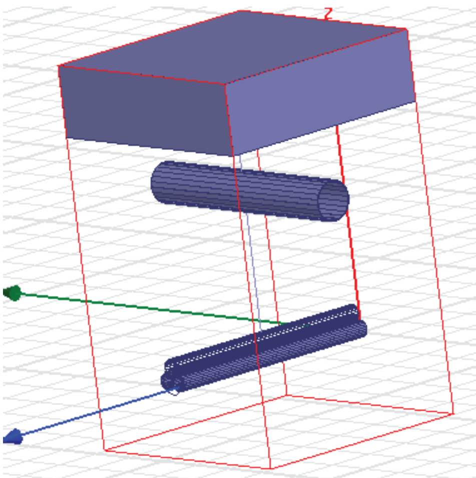

Figure 4 - Initial Configuration of Cable and Pipeline

3.1 Simulation Results

Since the variation of voltages induced on the steel pipe with the workspace is small, in millivolt, compared to the cable voltage in kilovolt, the simulation does not automatically display the variation graphically. Thus, these voltage profiles have been extracted from the simulation and plotted.

Figure 5 shows the voltage plot of the induced voltage along the steel pipe. The induced voltage variation along the length of the steel oil pipeline was determined and plotted for the stated apparent accuracy, but with the number of passes in the simulations constrained to be not less than a specific number, from 1 to 7, in successive simulations.

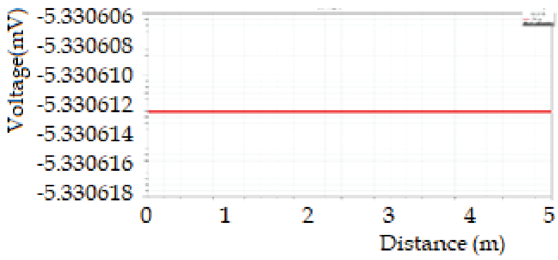

Figure 5 - Plot of Voltage vs. Distance Along the Steel Pipe

Figure 6 shows the voltage variations with distance along a vertical line across the centre of the topmost conductor to the steel pipe. As expected, the voltage profile is seen to rise from zero at the centre of the trefoil to the assigned voltage of 180 kV across the thickness of the conductor, as expected. The voltage immediately fell to an unobservable value on either side of the conductor.

3.1.1 Effect of Minimum Number of Converged Passes

The first simulation appeared to give the desired accuracy within one converged pass. The plot of induced voltage versus distance along a vertical line starting from a point just above the upper most cable (above the HDPE insulation of the cable) up to the steel pipe was obtained from the simulation and the plot of voltage versus distance along the steel pipe, and across the centre of top-most cable up to the steel pipe are shown in Figure 5 and Figure 6, respectively.

These figures show that the voltage induced in the oil pipeline, along the length considered in the simulation, is virtually constant at around 5 mV (possibly the variations seen are numerical errors rather) and that the voltage induced varies from around 10 mV near the sheath of the high voltage cable, to around a steady value of -5 mV along the length of the steel oil pipeline. This confirms that the simulation can handle a range of voltages from kilovolt to millivolt accurately.

As the calculated induced voltage was much less than 0.85 V, which is the standard safe margin usually adopted, it was encouraging.

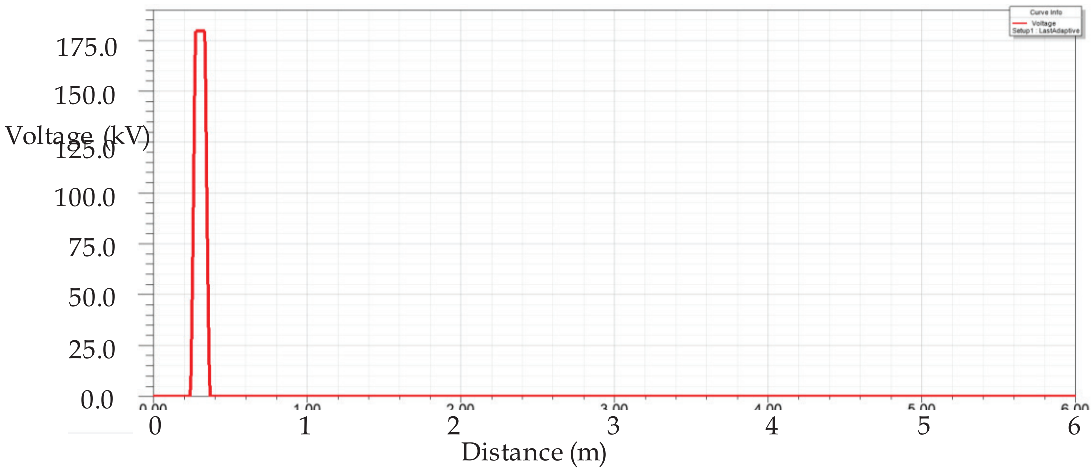

Figure 6 - Plot of Voltage vs Distance along Vertical Line Across the Centre of Top-Most Cableup to the Steel Pipe

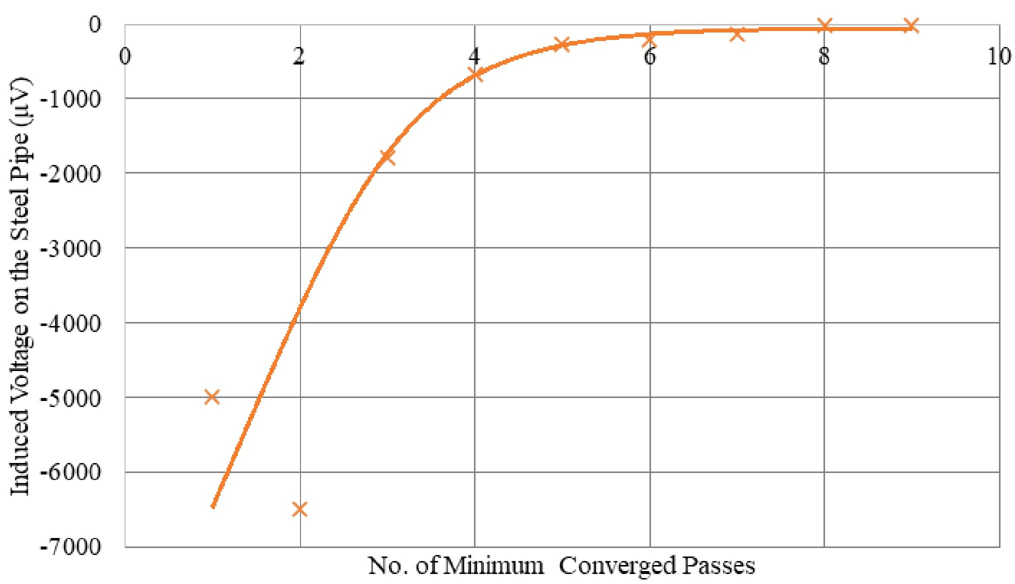

Figure 7 - Variation of Induced Voltage with Number of Converged Passes

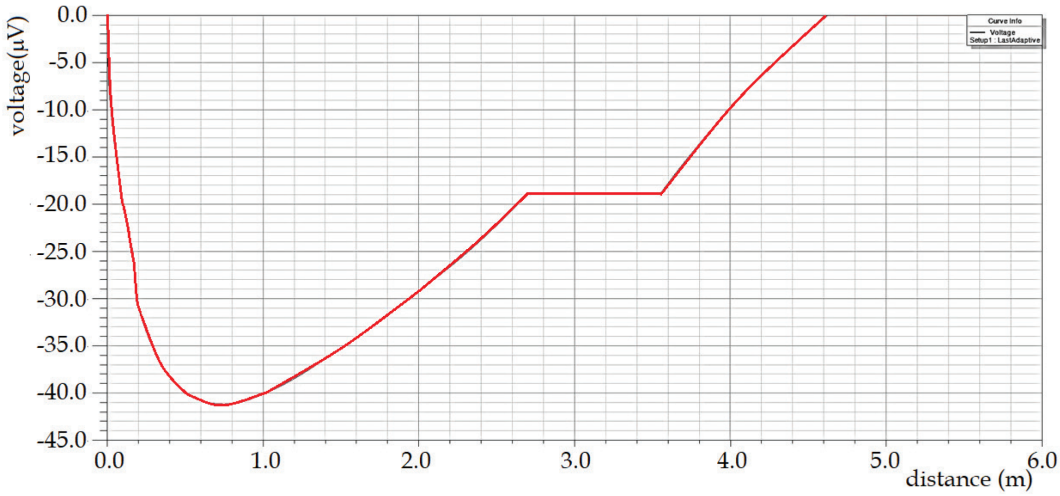

Figure 8 - Plot of Voltage vs. Distance along a Vertical Line Starting from a Point of the Topmost Cable Sheath to the Air Layer with Converged Passes Set to 9

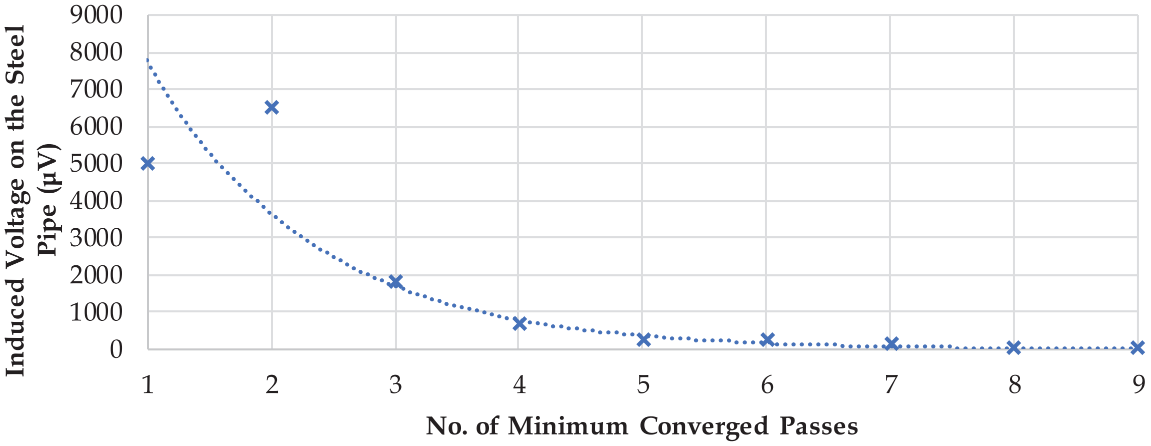

Figure 9 - Variation of Induced Voltage with Number of Converged Passes with Negative Peak Voltage at the Topmost HV Cable

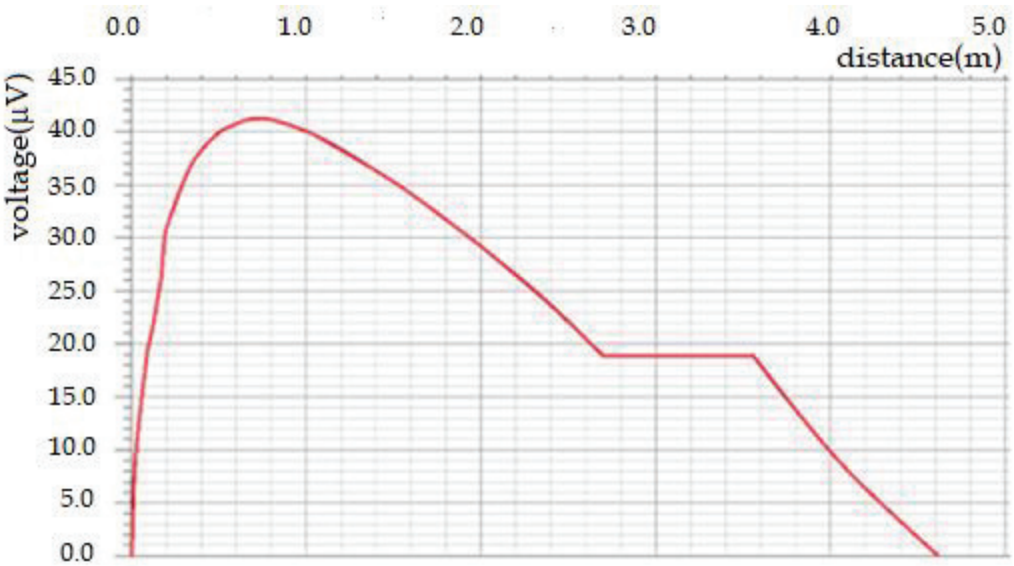

Figure 10 - Plot of Voltage vs. Distance along a Vertical Line Starting from a Point of the Topmost Cable Sheath to the Air Layer for 9 Converged Passes with Negative Peak Voltage at the Topmost HV Cable

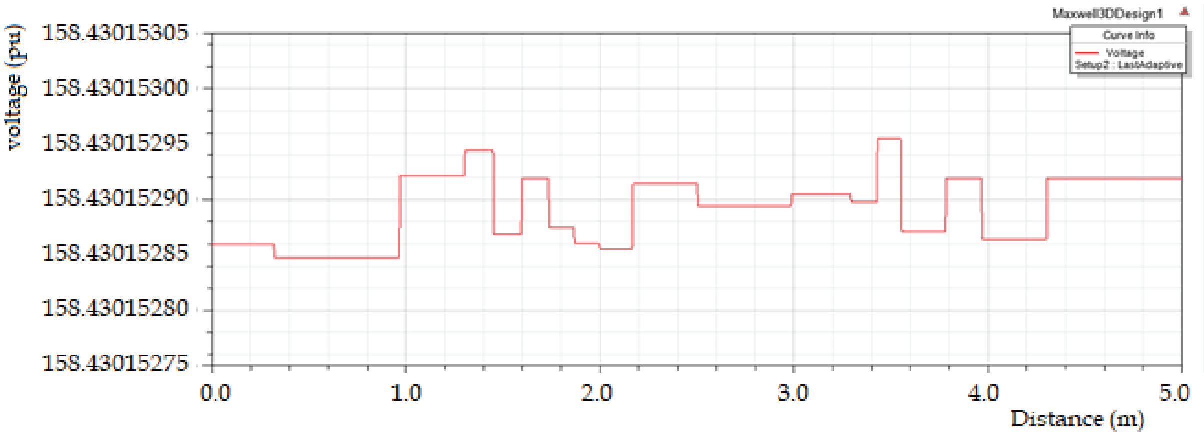

Figure 11 - Plot of voltage of a Line along the Surface of Steel Pipe-2

However, doubts arose as to possible inaccuracy as convergence was reached in just 1 pass. Thus, the simulations were repeated with constraints put on the minimum number of passes to converge, varying from 2 to 9, to see the effect on the solution accuracy. The same patterns were observed.

The results of the different minimum number of passes are presented in Table 3.

Table 3 - Test for Convergence

Minimum number of passes for convergence	Induced Voltage on steel pipe
1	-5000 μV
2	-6500 μV
3	-1800 μV
4	-672 μV
5	-269 μV
6	-217 μV
7	-132 μV
8	-22 μV
9	-19 μV

Figure 7 indicates that the solution for the induced voltage on the steel oil pipe settles at around -19 μV. The plot of voltage versus distance along a vertical line starting from the topmost cable sheath to the steel pipe was obtained from the simulation with minimum number of converged passes set to 9 and is given in Figure 8. This figure too shows that the voltage at the steel pipe is constant at around -19μV.

3.1.2 Simulation with Negative Voltage in Topmost Cable

Next, the extreme end of the arrangement was simulated with the top phase excited to negative peak AC voltage (-180 kV) and bottom two phases excited to positive half peak voltage (-90 kV). All other settings and parameters were maintained similar to the previous scenario.

This scenario was also simulated with a minimum number of converged passes from 1 to 9 and the plot of induced voltage on steel pipe is given in Figure 9. The plot of voltage versus distance along a vertical line starting from the topmost cable sheath to the steel pipe was obtained from the simulation with minimum number of converged passes set to 9 and is given in Figure 10. Figure 11 shows a plot of voltage induced along the surface of steel pipe 2. Close examination shows that while the average voltage is 158 μV, the voltage along the steel pipe is a constant and the apparent fluctuations are in the region of picovolt, indicating that the simulation has handled the range of voltages from kilovolt to millivolt accurately. The fluctuations seen are a numerical error rather than an actual variation.

The plot of voltage vs distance along the steel pipe after 9 converged passes is also shown in Figure 12. It is observed that these values are exactly the positive values of those obtained for the previous scenario as negative values.

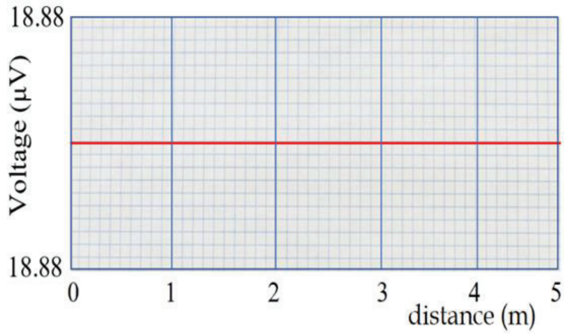

Figure 12 - Plot of Voltage vs Distance along the Steel Pipe for 9 Converged Passes with Negative Peak Voltage at the Topmost HV Cable

3.1.3 Effects of Conductivity and Relative Permittivity of Soil

A sensitivity analysis was also carried out with different conductivity and relative permittivity for the soil. The soil conductivity was changed between 0.1 S/m and 0.001 S/m but no change was observed in the steel pipe induced voltage value. Similarly, soil relative permittivity was changed from 5 to 25 with negligible change.

3.2 Simulation of the Actual Scenario

Having been satisfied that the simple configurations could be satisfactorily run, the actual scenario of 6 oil pipelines running in parallel and the 4 trefoil underground cables running perpendicular, as shown in Figure 13 was considered.

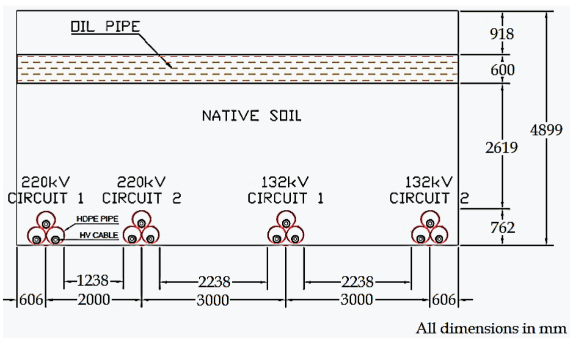

Figure 13 - Actual Arrangement of HDPE Pipes Enclosing each High Voltage Cable and Oil Pipe

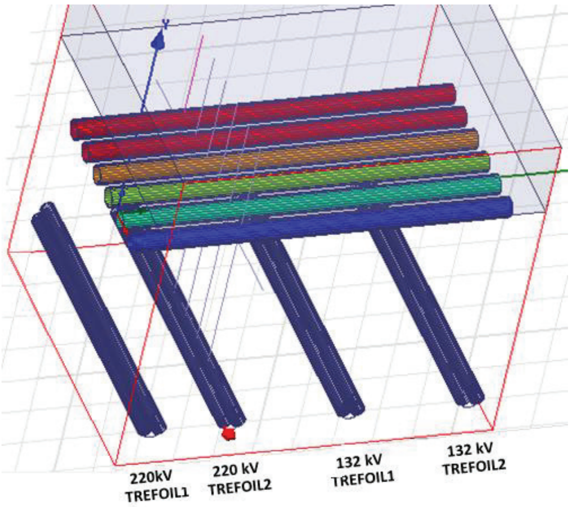

Figure 14 - Simulation of the Actual Scenario

For this simulation the pipe length was considered as 9.5 m and cable length as 7.5 m.

Figure 14 shows the simulation model for the actual scenario. The worst-case anticipated simulation was carried out with topmost cable having an instantaneous voltage of 180 kV and the bottom two trefoil cables having a voltage of – 90 kV in the case of 220 kV transmission voltage, and with topmost cable having an instantaneous voltage of 108kV and the bottom two trefoil cables having a voltage of – 54 kV in the case of 132 kV transmission voltage. To avoid end effect errors, the sheaths were earthed at one end and the centre of the trefoil was considered to be 0V. The soil was considered with representative values of relative permittivity of 10 and conductivity of 0.01S/m. This was actually checked to verify the accuracy of the simulation. Figure 15 shows the plot of voltage distribution along vertical lines through the individual steel pipes.

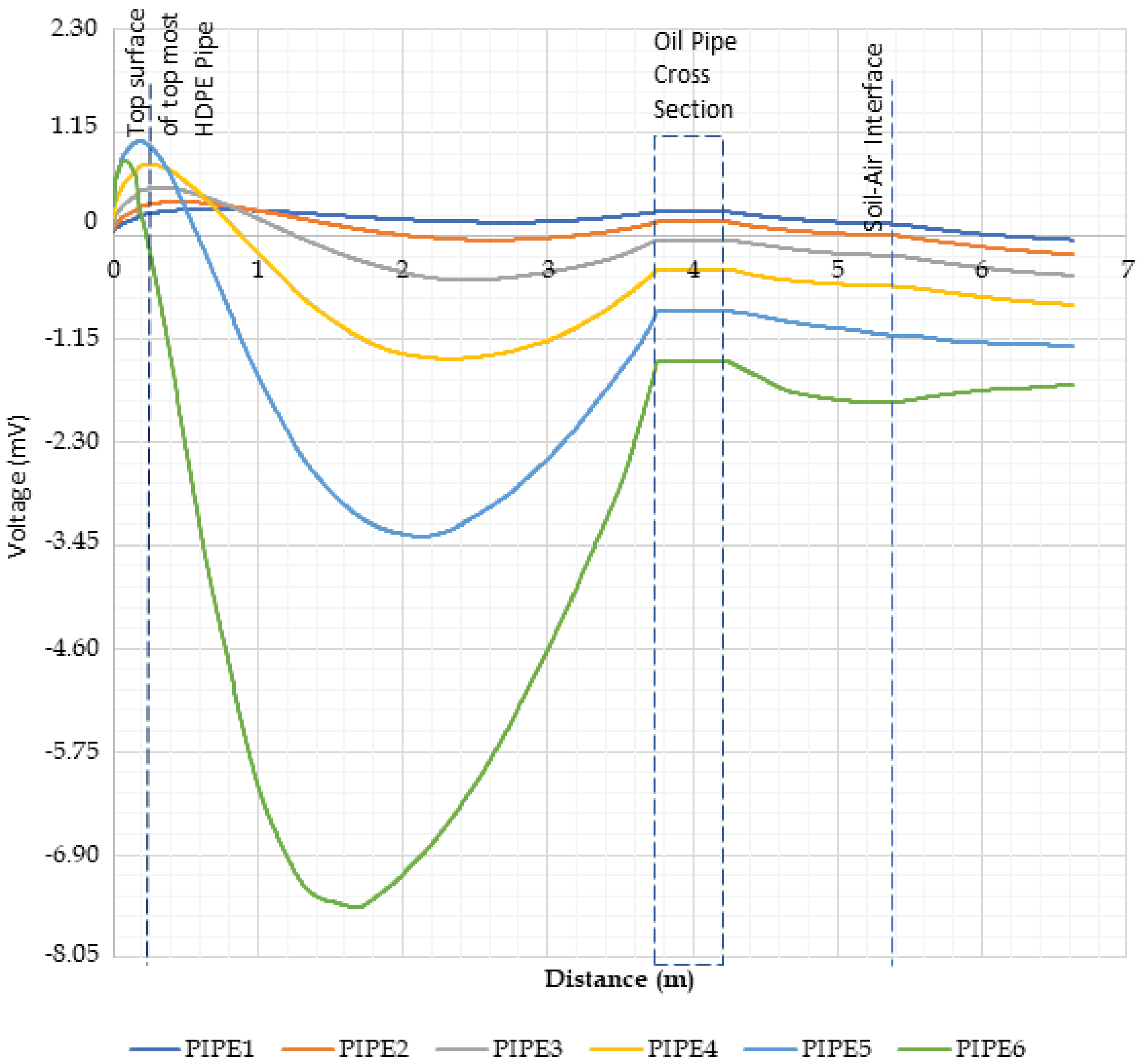

Figure 15 - Plot of Voltage Distribution along Vertical Lines through all the Steel Pipes

The analysis of the voltages induced in the individual pipelines has been carried out without considering cathodic protection given to the individual pipelines. Since the induced voltages across individual pipelines are in the range of 0.2 mV to –1.4 mV, any given cathodic protection to the steel pipes would not be adversely affected by these induced voltages. As the results obtained were considered acceptable, all parameters were simulated as closely as possible to the actual ground situation.

3.2.1 Effect of Weather Conditions

Simulations were run under normal, dry, and wet conditions by changing the soil parameters as shown in Table 4 and the corresponding induced voltage on the steel oil pipe as given in Table 5.

Table 4 - Effect of weather conditions and soil

	Dry	Normal	Wet
Relative permittivity	5	10	50
Conductivity (S/m)	0.005	0.01	0.05

Table 5 - Effect of Weather Conditions on Steel Pipe Induced Voltage

Weather condition	Peak value of induced voltage on steel pipe surface (μV)
Dry	12.7
Normal	18.9
Wet	67.0

It is seen that all the values of induced voltage on the steel pipe are well within the acceptable range.

4. Conclusions

The induced voltage on buried steel pipes due to the later addition of high voltage underground cables crossing the pipelines perpendicularly has been analysed using Ansys Maxwell's electromagnetic software. A case study of the introduction of two 220 kV underground cables from Biyagama - Kelanitissa line and two 132 kV underground cable circuits from Kelanitissa - Kolonnawa running perpendicular to six underground petroleum carrying steel pipelines has been investigated to study its influence on existing impressed current cathodic protection of steel pipelines. It is usual to give a negative direct voltage of around 850 mV to steel pipelines to efficiently control corrosion. The study has shown that the maximum induced voltage is less than 1.5 mV which has no adverse effect on any existing impressed current cathodic protection.

It is to be worth noting that the construction of the New Kelani Bridge got Sri Lanka Cabinet approval in December 2016, the present study on the induced voltage took place in early 2018. After the successful completion of the induced voltage study presented in this paper, the high voltage cables were installed and commissioned in early 2019. The New Kelani Bridge has also been now completed and there has been no complaints received as to the loss of cathodic protection of the steel pipelines. It was physically not possible to access the cables after installation to measure the actual induced voltages.

Acknowledgement

Authors wish to acknowledge the assistance given by the staff of the Department of Electrical Engineering of the University of Moratuwa, Ceylex Engineering Pvt. Ltd. and the Ceylon Electricity Board in gathering information for the paper. In particular, the contributions of Eng. Malaka Gunasekera are gratefully acknowledged.

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