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# Mitigation of Interference in Impressed Current Cathodic Protection

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Author AIO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author TAB managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.*

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## ABSTRACT

This paper considers the strategies for the mitigation of the interference of Stray Current (SC) on Impressed Current Cathodic Protection of the American Petroleum Institute specification API 5L grade B pipeline carrying liquefied gas. SC shifts cathodic protection from its designated negative value, and hence expose the pipeline to corrosion. A model for SC was developed and then applied in MATLAB. From the given conditions of operation, an SC of 0.74 mA was obtained, with parametric simulation indicating a rise in SC as anode current output rises. On the other hand, the consequence of the distance of different pipeline from the ground level shows an inverse relationship, which is attributed to the resistance offered by the ground. In order to mitigate the influence of SC interference, two methods have been proposed in this study, the first being anode current reduction or source removal and the second option is increasing distance from the ground bed. To effectively mitigate against the stray current, the pipeline should be sufficiently buried over

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a distance of 5 m away from the ground bed, while the anode current should be operated as low as 3.5 mA, or better still the interfering source should be removed on the ground that the interfering source was installed after the installation of the protected pipeline.

*Keywords: MATLAB; simulation; mitigation; pipeline; corrosion.*

## 1. INTRODUCTION

The impressed current cathodic protection (ICCP) is an approach employed in cathodic protection (CP) system, and it uses an electricity source to propel the current from a very noble material in order to shield the pipeline [1]. As compared to galvanic anodes, ICCP anodes are typically better than the pipeline. The three major components in a rectifier are a transformer, stack, and cabinet. The purpose of the transformer is to safely separate the incoming AC voltage (primary side) from the secondary side, which is adjusted to control the output voltage of the rectifier. Impressed current can meddle with other metal materials in the area and lead to coating removal, which results in rapid rusting of the Foreign Pipeline (FP) [2]. Current flowing in a pipeline structure can be an indication of serious trouble, causing corrosion or even harm to people working with it. Buried pipelines experience interference caused by straying current [3]. The project aims at specifying and analysing some techniques that can be deployed for the mitigation of stray current interference of ICCP systems on buried pipelines, and propose the best practical method. The following will be achieved to actualized the aims [4].

i. To carry out analysis on the interference of SC arising from the action of nearby ICCP systems on buried pipelines.
ii. Identify the various methods that can be employed to mitigate against SC interference-effect.
iii. Analyse the various techniques obtained, to see the one that has the best shielding effect from stray currents.
iv. Present the best practical means for the mitigation of interference in ICCP systems.
v. Carry out an analytical simulation that depicts the identified technique as the most efficient method of mitigation of interference in ICCP systems.

A key challenge in pipeline operations is the interference with CP. This investigation was undertaken to explore some methods that can be employed in mitigating against the influence of SC arising from deviated current in an ICCP system and after that, propose the best practical alternative technique [5]. Having identified the best effective technique for mitigating interference, the industry will have the option of saving money and time; and maintain the reliability of their asset over a more extended duration just by employing the proposed technique. More so, academia and researchers, in general, would have an option to consider in detail [6].

In this work, the analysis was carried out on the following:

i. Buried steel pipelines of API 5L grades are transporting natural gas or crude oil.
ii. Electrical interference due to the operation of ICCP systems in nearby cathode protected systems.
iii. Deep well bed anodes connected to transformer/rectifier systems.
iv. Coated sections of pipeline systems.
v. Direct current (DC) operated impressed current systems.
vi. The interferences considered are those in pipelines that have been designed, installed, commissioned and in operation.

However, this work is limited to the following areas:

i. Interference originating from SC, although other forms of interference do exist, such as high tension overhead.

Buried steel pipelines in compliance with the American Society of Mechanical Engineers specification ASME B31.8, ASME B31.4 requirements, and API standards for transporting natural gas or crude oil

## 2. MATERIALS AND METHODS

### 2.1 Research Design

The research approach adopted in this project is by developing an empirical mathematical model and analytical simulation performed in MATLAB to solve the problem of interference in a foreign pipeline (FP) due to the action of an ICCP system.

## 2.2 Data Collection Places

Primary data were collected from the field to accomplish the set objectives of this research. These data were collected from pipelines that are currently in operation in Um Qasr Field, Iraq.

### 2.2.1 Input parameters

The input data needed for the analysis and simulation includes, among others:

i. The distance of pipeline from anode ground bed
ii. Anode current output (ACO)
iii. Soil resistivity
iv. Length of the anode or buried depth of anode
v. Pipeline operating characteristics
vi. Pipeline dimensions
vii. Field or area/region considered

Table 1 shows the input data used for the mathematical model and analytical simulation.

### 2.2.2 Output parameter

The output parameter is the stray current (SC) in the earth at a specified distance from the impressed current bed.

## 2.3 Method of Data Analysis

The approach followed is an empirical model that incorporates the essential features influencing the interference of ICCP systems, which is subsequently followed by MATLAB simulation.

## 2.4 Mathematical Model

Various electrical systems depend on the ground as a conducting means, either for transmitting electrical power as with CP or as electrical grounding. Others such as electrified transport systems cannot be effectively isolated from the ground. Notwithstanding, any electrical structure in interaction with the ground is a likely source of SC [7]. As presented in Fig. 1. current incoming to the earth at a point A can take various parallel paths accessible to get to another point B.

The current takes available routes and is in reverse proportionality to the resistance offered by the route [9]. If a point A is taken as an impressed current bed connected to the positive end of a transformer or rectifier and another point B is a structural pipeline associated with the negative end, the parallel routes may all be the same in resistance, in such a case, all the currents are similar [10]. This is merely possible inconsistent soil where both points B and A are far-off, and the pipeline has no linear resistance. However, if the ground resistivity varies or the

**Table 1. Input data for the mathematical model and analytical simulation**

| Item | Symbol | Units | Value |
|---|---|---|---|
| Distance between protected pipeline and bed | - | m | 150 |
| Anode Current Output | I | A | 3.5 |
| Distance between foreign pipeline and bed | x | m | 5 |
| Soil Resistivity, ρs (Ω – m) | $\rho_s$ | Ω- m | 2200 |
| Length/depth of Anode | L | m | 33 |
| Pipeline grade | - | - | API 5L Gr. B |
| Pipeline service | - | - | Liquefied gas |

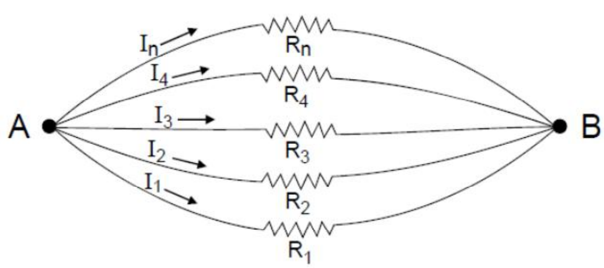


**Fig. 1. Current incoming to the earth at a point A and moving in parallel paths to another point B [8]**

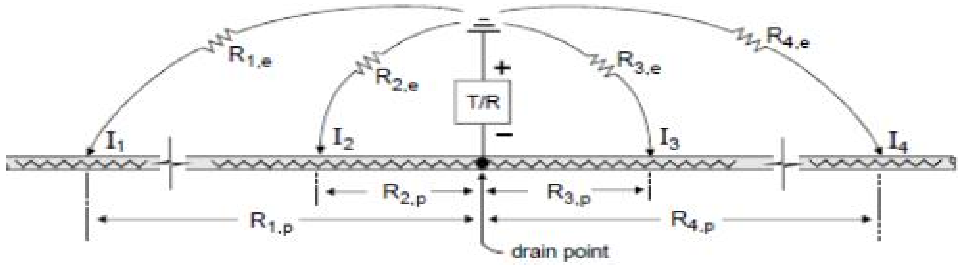


**Fig. 2. Parallel current routes in a pipeline CP system [8]**

pipe has related resistance, the current routes will show unequal resistances. This CP system is displayed in Fig. 2.

It is evident that every current route is made up of resistance in the earth ($R_e$) and resistance in the pipe $R_p(\Omega)$ from the position of current pick-up [11]. Hence, the overall resistance $R_{t,i}\ (\Omega)$ is different for each unique path, as represented in Equation (1).

$$R_i = R_{e,i} + R_{p,i} \tag{1}$$

Since the span of each path is different. The pipe and earth in any path flung from the drain. Hence, the resistance of the path will rise with a distance from the drain. The aggregate of the current $I_i(A)$ path is shown in Equation (2).

$$I_i = \frac{R_{t,n}}{R_i} I_t \tag{2}$$

where, $I_t(A)$ is the total current and $R_{t,n}(\Omega)$ is the parallel sum of all the paths resistance given in Equations (3) and (4), respectively

$$I_t = I_1 + I_2 + I_3 + \cdots + I_n \tag{3}$$

$$\frac{1}{R_{t,n}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} \tag{4}$$

Where, $I_i(A)$ and $R_i(\Omega)$ are the $i$th path current and resistance respectively?

In stratified soil where the resistivity or cross-sectional of the layers are dissimilar, even current routes of equal length do not have equal resistances [12]. This CP system can be seen in Figs. 3 and 4, respectively.

It is common than not for soil geology to be stratified in both vertically and horizontally directions, and for the current in the low resistive soil to be equitably bigger than in the moderate and high resistive soils [13]. The resistance offered by the current routes in a vertically stratified soil only depends not on soil resistivity but also the sectional area of the current route given as in Equation (5).

$$R_{i,e} = \rho_s \frac{L}{A_{x,s}} \tag{5}$$

Where, $R_{i,e}(\Omega), \rho(\Omega m), L(m)$ and $A_{x,s}(m^2)$ are the resistance of the current route, soil resistivity, length of the route taken by current and sectional area of soil, respectively.

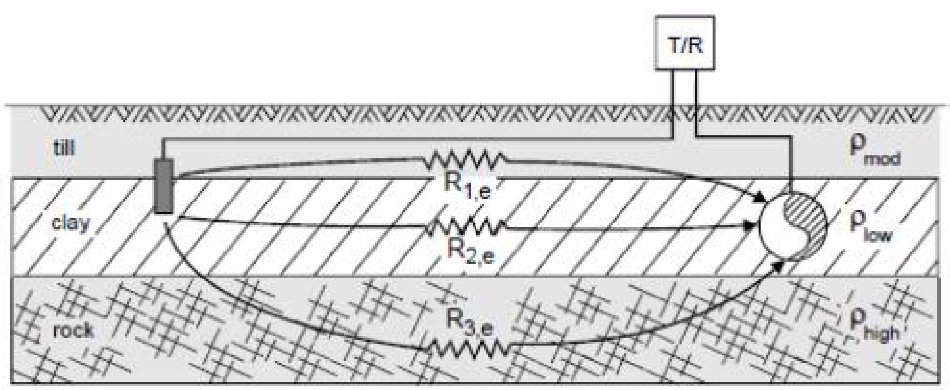


**Fig. 3. Parallel current routes in vertically stratified soil conditions [13]**

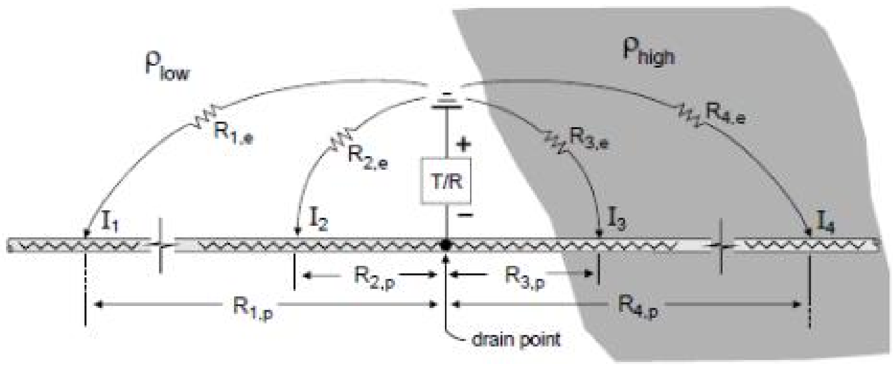


**Fig. 4. Parallel current routes in horizontally stratified soil conditions [8]**

Soil resistivities ($\rho_s$) are normally within $10^3 - 10^6$ Ω-cm, however metal resistivities ($\rho_m$) are within $10^{-5} - 10^{-6}$ Ω-cm. Hence, metal to soil resistivity ratio can be within $10^{-8} - 10^{-12}$. This means for soil resistivity as high as $10^5$ Ω-cm, metal material in the earth having a sectional area of say 100 $cm^2$ is equal in resistance to a cross-section of soil given in Equation (6).

$$\frac{\rho_m}{\rho_s} = \frac{A_{x,m}}{A_{x,s}} \tag{6}$$

Where, $\rho_s$ and $\rho_m (\Omega m)$, are the resistivities of soil and metal, respectively; $A_{x,s}$ and $A_{x,m} (m^2)$ are the cross-sectional area of soil and metal, respectively. Hence, $\frac{\rho_m}{\rho_s} = 10^{-12}$ and $A_{x,s} = 10^{10}$ $m^2$. This means a metal with a 0.01 $m^2$ sectional area is equivalent to soil with a cross-sectional area of $10^{10}$ $m^2$ if soil resistivity is $10^6$ Ohm-cm. This implies that when a metal is present in the earth, it poses a very potent current path; thus, resulting in an SC ($I_s$) in the metal structure as indicated in Fig. 5.

The SC is chosen on the foreign pipeline (FP) where it is impacted by ground bed anode potential gradient [14]. If no straight electronic path is present between the FP and the protected pipeline, the electric current will be released from the structure distant from the pick-up region. The total SC in the structure results from the resistance of the SC route and the driving voltage left behind at the point where the foreign structure overlaps the anode potential.

Current from an electrode, placed uprightly in the earth, produces a drop in voltage in the soil closer to the electrode creating equipotential surface normal to the current route in Fig. 6.

From Fig. 6, the voltage drop $V_{a,x}(V)$ is represented in Equation (7).

$$V_{a,x} = \frac{I\rho_s}{2\Pi L}\left[\ln\left(\frac{L+\sqrt{L^2+x^2}}{x}\right)\right] \tag{7}$$

Where, $V_{a,x}$, $I(A), L(m), \rho_s(\Omega m)$ and $x(m)$ are voltage rise, anode current output, length of the anode, soil resistivity and distance from the anode, respectively.

An analogous voltage drop does occur in the neighbourhood of a naked pipeline given in Fig. 7.

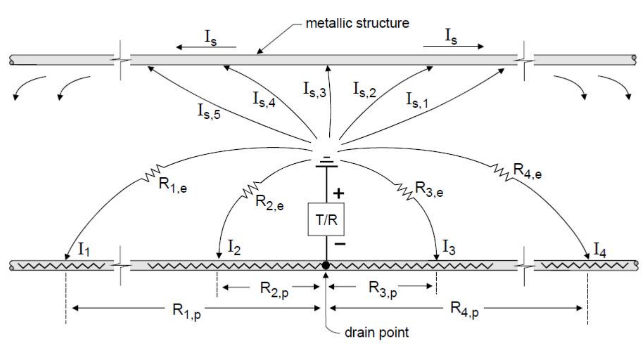


**Fig. 5. Stray current (SC) in a metallic structure parallel to a CP structure [8]**

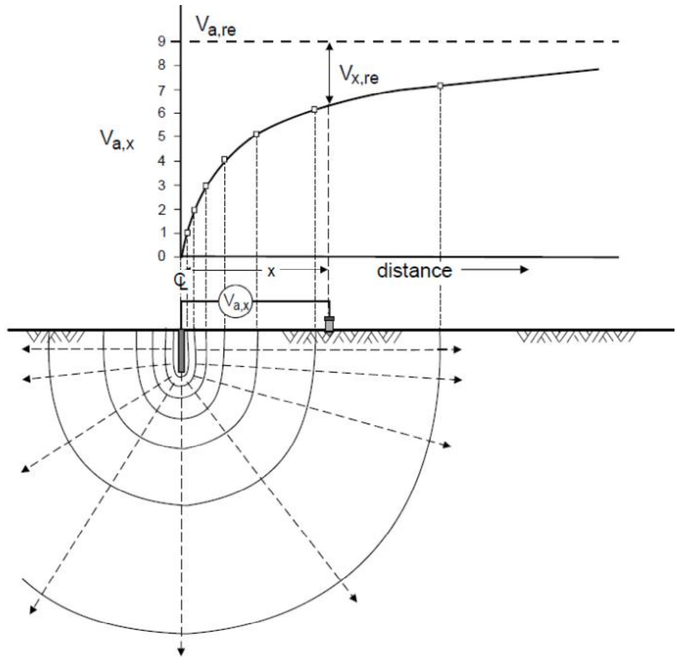


**Fig. 6. Voltage against distance from a vertically oriented anode [8]**

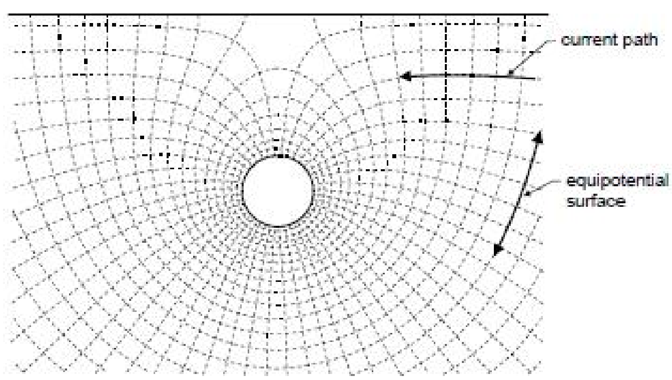


**Fig. 7. Voltage gradient in the earth around a CP bare pipeline [8]**

The cathodic protection (CP) circuit can be modelled as a series of resistance circuit, as presented in Fig. 8.

Where, $\mathrm{R_{c,a}}$ and $\mathrm{R_{c,p}}(\Omega)$ are anode and pipe cable resistances, respectively; $\mathrm{R_{a,re}}$, and $\mathrm{R_{p,re}}(\Omega)$ are anode and pipe resistances to remote earth, respectively.

Similarly, a parallel path can be introduced as in Fig. 5, if the metallic pipeline intercepts the anode potential [6]. Fig. 9 shows the cathodic protection circuit model with the foreign structure intersecting the anode gradient.

Where, $\mathrm{R_{c,a}}$ and $\mathrm{R_{c,p}}(\Omega)$ are anode and pipe cable resistances, respectively; $\mathrm{R_{a,re}}$, and $\mathrm{R_{p,re}}(\Omega)$ are anode and pipe resistances to remote earth, respectively; $\mathrm{R_{s,re}}$, and $\mathrm{R_{s,re}}(\Omega)$ are foreign pipe resistance to earth in an SC pick-up area and pipeline resistance to distant earth, respectively; $\mathrm{R_s}(\Omega)$ is longitudinal resistance of pipeline between pick-up and discharge centres.

The existence of the foreign structure introduces a matching circuit into the model from whence the voltage drop between remote earth and point A is applied to the structure [15]. This procedure reduces the total resistance offered by anode to distant earth and weakens the CP beyond location A to $\mathrm{I_{cp}}$ by the amount $\mathrm{I_s}$ as in Fig. 10 and Fig. 11.

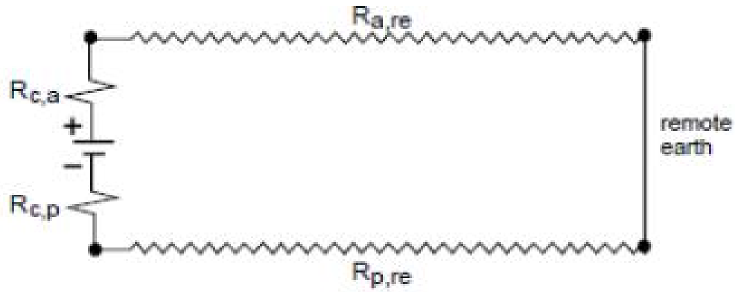


**Fig. 8. Cathodic protection circuit model [8]**

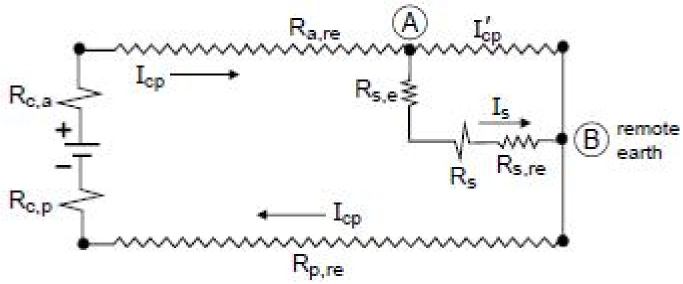


**Fig. 9. Cathodic protection circuit model with foreign structure intercepting the anode gradient [8]**

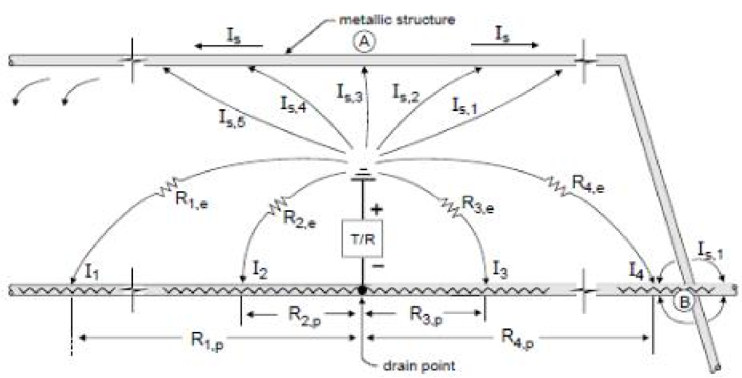


**Fig. 10. Stray current in a foreign pipeline that intercepts cathodic and anodic voltage gradient [8]**

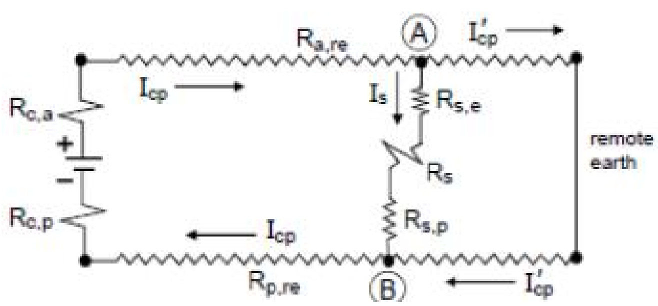


**Fig. 11. Cathodic protection circuit model with foreign structure intersecting anodic, cathodic voltage gradients [8]**

Where, $R_{c,a}$ and $R_{c,p}(\Omega)$ are anode and pipe cable resistances, respectively; $R_{a,re}$ and, $R_{p,re}(\Omega)$ are anode and pipe resistances to remote earth, respectively; $R_{s,re}$, and $R_{s,re}(\Omega)$ are resistance of foreign pipe to earth in a SC pick-up area and foreign structure resistance to remote earth, respectively; $R_s(\Omega)$ is longitudinal resistance of foreign structure between pick-up and discharge sites; $R_{s,p}(\Omega)$ is resistance of pipe to CP pipeline at discharge zone.

A foreign pipeline (FP) can also be exposed to an SC even if only it intersects the cathode potential gradient, as displayed in Fig. 12.

In such a situation, the affected structure picks up SC at distant earth A and conveys it to the junction where it releases it back to the interrupting structure [16]. This implies that a pipeline shielded by the technique of impressed current can cause interruption on crossing metals that are otherwise far from impressed current beds.

As shown in Fig. 13, SC can arise in an external metal system being impacted by the cathodic or anodic potential gradient created by a pipeline impressed current cathodic protected structure. The amount of the current is proportional to the potential difference between the pick-up point and discharge point and varies inversely to the resistance of the intruding current path [8].

## 2.5 Stray Current Derivation from Voltage Rise

Equation (7) presents the earth voltage rise as against remote earth. However, it does not stipulate the SC that will be developed in an FP that passes the area of the dominance of the ground [17]. The resistance offered to the stray current is given in Equation (8).

$$\rho = \frac{RA}{L} \tag{8}$$

Where, $\rho(m)$, $A(m^2)$, $L(m)$ and $R(\Omega)$ are soil resistivity, cross-sectional area, length and resistance, respectively.

If we consider a unit cross-sectional area of soil, A = 1 $m^2$, and a soil section of a unit length, it will give L = 1 m (forming a cube with perfectly conductive contact on opposite faces). Therefore, the resistance of this section in ohm is numerically equal to the resistivity of the composite material in ohm-meter, and Equation (6) becomes ρ = R (Ω-m).

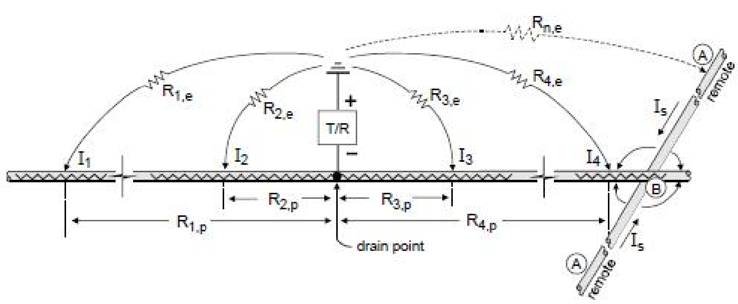


**Fig. 12. Stray current in an FP that intersects the CP gradient [8]**

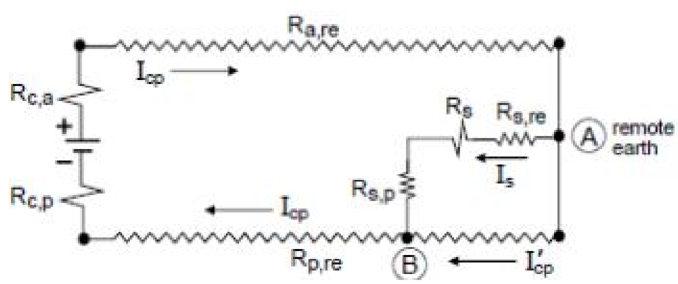


**Fig. 13. Cathodic protection model for foreign structure intersecting the cathodic voltage gradient [8]**

The stray current that will be developed in one unit of area is given in Equation (9)

$$I_s = \frac{I}{2\Pi L}\left[\ln\left(\frac{L+\sqrt{L^2+x^2}}{x}\right)\right] \quad (9)$$

Where, $I_s(A), I(A), L(m)$ and $x(m)$ are stray current, anode output current, length of anode and distance from the anode, respectively.

Equation (9) presents the value of stray current at a distance of one meter (1m). Since current is inversely proportional to distance, the value of current at a further distance can be estimated, say 50m away. The Current is inversely proportional to the distance as shown in Equation (10)

$$I \propto \frac{1}{d} \quad (10)$$

Where, $d(m)$ is the distance?

Combining Equations (9) and (10) provides the value of the SC at any distance d away in Equation (11).

$$I_s = \frac{1}{2\Pi dL}\left[\ln\left(\frac{L+\sqrt{L^2+x^2}}{x}\right)\right] \quad (11)$$

## 3. DATA PRESENTATION

This section presents and discusses the results which were gotten from the mathematical analysis carried out on stray current (SC) interference on a foreign pipeline, due to the operation of ICCP system on a nearby buried pipeline. Results are presented in tables and plots and afterwards discussed in section 3.1 to 3.2.

### 3.1 Mathematical Modelling Results

Results gotten from the mathematical models formulated in the preceding section are presented in Tables 2 and 3, respectively. Table 2 shows the results of SC interference on different pipelines based on their distance from the ground bed. These results were based on a 5 L of liquefied gas carrying pipeline of API grade B. The soil resistivity was identified as 2200 Ω–m, making it good enough to resist the flow of stray current, thereby minimising corrosion. Table 3 shows a similar result but with the effect of anode current output. A base result of 0.74 mA of stray current was obtained for a working condition of 3.5 A of anode current output for a foreign pipeline whose distance is 5m from the ground level.

### 3.2 Simulation of Relevant Parameters

The system was described and analysed based on the parameters affecting the degree of stray current (SC) interference. Fig. 14 shows the influence of one of such parameters, increasing distance between the foreign pipeline and the ground bed. From Fig. 14. the SC interference decreases with an increase in depth from the ground bed. This procedure was expected as the ground provides sufficient resistance to the flow of dynamic stray current with increasing distance. This trend does agree with the investigation carried out by Allahkaram *et al.* [1] on “corrosion rate and an innovative corrosion strategy for gas pipelines affected by dynamic SC” [18].

Fig. 15. shows the influence of the anode current output (ACO) on SC interference in an ICCP. Increase in ACO results in a corresponding increase in the SC. This Anode Current Output ascribed to the effect of current on the stray current interference. To have a minimal interference of deviated current on the protected structure, the ACO should be reduced to a tolerable limit.

### 3.3 Proposed Stray Current Mitigation Options

Once Stray Current (SC) interference is determined, the mitigation technique further depends on the distance and gravity of the interference, and on capital involvement of the mitigation choices. Different methods have been employed to reduce the damaging effects of dynamic stray current on the ICCP system [19]. However, two more methods have been proposed in this work and discussed in the subsections 3.3.1 and 3.3.2 that proceed. They include an increasing distance of foreign pipeline from the ground bed and source removal or source output reduction.

#### 3.3.1 Source removal or source output reduction

The current at the anode of the protected pipeline (i.e. the current emanating from the metallic side that is more prone to corrosion), affects the quantity of stray current by increasing it. When this value is sufficiently reduced, the stray current significantly reduces along with it.

**Table 2. Stray current interference on different pipelines based on their distance from the ground bed**

| The distance of protected pipeline from ground bed (m) | Anode Current Output (A) | The distance of foreign pipeline from ground bed (m) | Soil Resistivity, ρs (Ω – m) | Length/ depth of Anode (m) | Pipeline Grade | Pipeline service | Stray Current (A) |
|---|---|---|---|---|---|---|---|
| 150 | 3.5 | 1 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.003200 |
| 150 | 3.5 | 1.3 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.002500 |
| 150 | 3.5 | 1.5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.002100 |
| 150 | 3.5 | 1.8 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.001900 |
| 150 | 3.5 | 2.1 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.001500 |
| 150 | 3.5 | 2.5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.001100 |
| 150 | 3.5 | 2.8 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000740 |
| 150 | 3.5 | 3.0 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000650 |
| 150 | 3.5 | 3.4 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000610 |
| 150 | 3.5 | 3.7 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000550 |
| 150 | 3.5 | 3.8 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000510 |
| 150 | 3.5 | 4.0 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000440 |
| 150 | 3.5 | 4.2 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000400 |
| 150 | 3.5 | 4.6 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000330 |
| 150 | 3.5 | 5.0 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000290 |
| 150 | 3.5 | 5.4 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000230 |
| 150 | 3.5 | 5.9 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000170 |
| 150 | 3.5 | 6.3 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000110 |
| 150 | 3.5 | 6.5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000042 |
| 150 | 3.5 | 6.9 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000021 |

**Table 3. Stray current values on a pipeline based on different anode current outputs**

| The distance of protected pipeline from ground bed (m) | Anode Current Output (A) | The distance of foreign pipeline from ground bed (m) | Soil Resistivity, ρs (Ω – m) | Length/ depth of Anode (m) | Pipeline Grade | Pipeline service | Stray Current (A) |
|---|---|---|---|---|---|---|---|
| 150 | 15 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.003200 |
| 150 | 12 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.002500 |
| 150 | 10 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.002100 |
| 150 | 9.0 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.001900 |
| 150 | 7.0 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.001500 |
| 150 | 5.0 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.001100 |
| 150 | 3.5 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000740 |
| 150 | 3.1 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000650 |
| 150 | 2.9 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000610 |
| 150 | 2.6 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000550 |
| 150 | 2.4 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000510 |
| 150 | 2.1 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000440 |
| 150 | 1.9 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000400 |
| 150 | 1.6 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000330 |
| 150 | 1.4 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000290 |
| 150 | 1.1 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000230 |
| 150 | 0.8 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000170 |
| 150 | 0.5 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000110 |
| 150 | 0.2 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000042 |
| 150 | 0.1 | 5 | 2200 | 33 | API 5L Gr. B | Butane (C4) | 0.000021 |

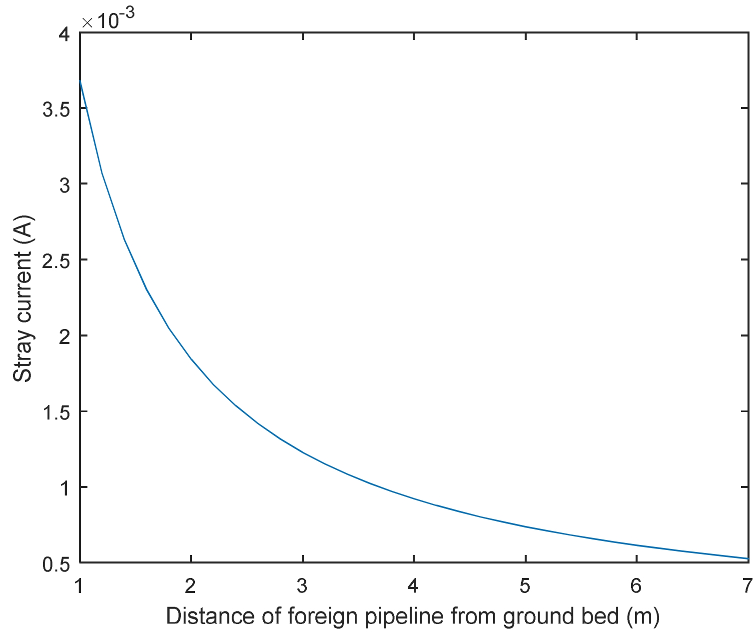


**Fig. 14. Effect of distance between foreign pipeline and ground bed on SC**

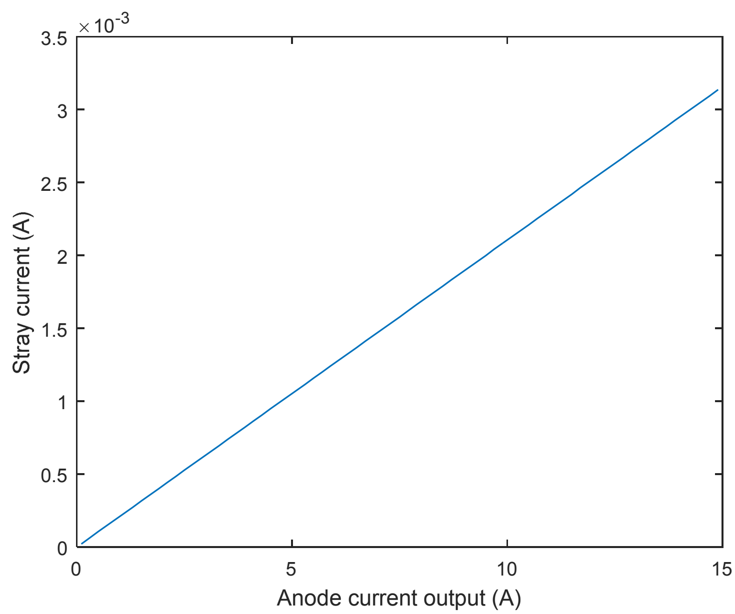


**Fig. 15. Effect of anode current output on stray current interference**

From the table of results, Table 3, an anode current value lower than 3.5mA has been proposed to reduce the amount of stray current produced effectively. The method of source removal poses to be an effective method of SC interference mitigation if the interfering pipeline is newly installed, but a difficult option if the interfering pipeline was present before the foreign pipeline.

### 3.3.2 Increasing distance of foreign pipeline from ground bed

Another way to mitigate against stray current influence in ICCP is by increasing the distance of the buried foreign pipeline sufficiently from the ground bed. Equation (11) is used to evaluate how remote a foreign pipeline must be to minimise the SC interference effects. It was observed from this investigation that pipeline buried sufficiently below the ground, at about 5m or more from the ground as evidence in Table 2, has a significantly reduced value of stray current. This technique is useful if the interference is due to the closeness of the foreign structure to the anode bed.

## 3.4 Other Mitigation Methods

Other methods include the use of isolating fittings, installation of a metallic shield close to the foreign pipeline, connection of galvanic anodes on the foreign pipeline at the point of SC discharge, connection of an impressed current system on the foreign pipeline at the position of stray current discharge, connection of a bond between the protected and foreign pipelines, and the use of coating.

### 3.4.1 Use of isolating fittings

The use of isolating fittings as an SC mitigation technique is a measure to increase the path resistance of the foreign pipeline, thereby minimising the stray current.

### 3.4.2 Installation of a metallic shield close to the foreign pipeline

The purpose of burying a metallic conductor is to intercept the SC and thereby provide another low resistance route for the SC different from the foreign pipeline route. Installing the metallic protection which may perhaps be a simple cable or metal, straight to the negative end of the protected pipeline transformer/rectifier would be most effective than connecting it directly to the pipeline. Installation of the metallic protection is most advantageous when foreign pipeline structure is produced of an amphoteric material or where cathodic disbondment is of great concern [20]. Fig. 16. shows a buried conductor cable acting as a shield to minimise the effect of SC.

### 3.4.3 Connection of galvanic anodes on the foreign pipeline at the location of SC discharge

When the region of SC liberation is minimal such as a region of pipeline crossing, and where total SC is less than one ampere, installing sacrificial anodes becomes very useful. When the anodes are placed along the protected pipeline. The anode resistance is minimised; hence, the SC in this path is maximised. The sacrificial anodes can also closely connect the protected pipeline’s cathodic potential gradient, thereby, increasing the amount of the interference current. The anodes can also be connected parallel to the foreign pipeline (FP) which reduces the anode circuit resistance, thereby, maximising the cathodic protection current. If the point of crossing of the FP is coated, the resistance route through the sacrificial anodes will be less than the FP resistance. Preferably, the sacrificial anodes are spread along the protected pipeline to minimise the resistance path so that the SC is a large portion of the combined stray current. The design lifespan of the sacrificial anode must consider the part of its total output that will be consumed by stray current.

There are benefits in using this technique, notably of which are:

- The foreign pipeline can have its CP independence.
- The sacrificial anode CP output current raises the extent of protection at the intersection as an added barrier if the interference increases.
- Maintenance needs are reduced as compared to a direct connection.

The drawback is that it is comparatively costlier when compared with a direct bond, and the interference mitigation size is relatively limited. To reduce large currents interference in the CP

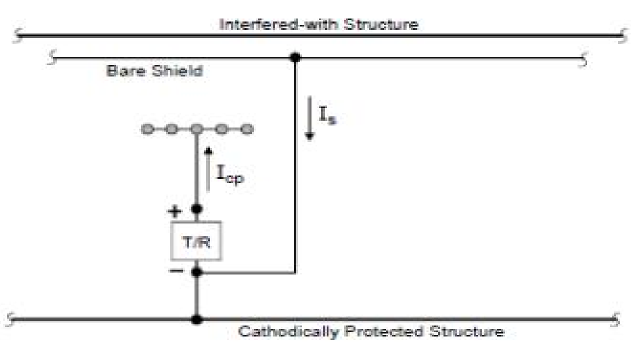


**Fig. 16. Use of buried conductor as protection to reduce SC Interference [8]**

system, but an impressed current system may be utilized with the drain at the intersection, but the ground bed is secluded from piping systems. This approach is depicted in Fig. 17.

### 3.4.4 Connection of an impressed current system on the foreign pipeline at the position of stray current discharge

The connection of an impressed current distribution system at discharge locations can be a viable means of recompensing the SC interference. Care should, however, be considered to guarantee that the impressed current system does not create a disturbance on the protected system.

### 3.4.5 Connecting a bond to hold protected and foreign pipelines

One of the commonest SC alleviation methods is the connection of a bond at the position of highest SC discharge to hold the two pipelines. This bond usually is possessing some form of resistance. This method is similar to the method of installing galvanic anodes except for the bond resistance supplanting the sacrificial anode resistance in the circuit. The resistance is obtained by noting the potential of the foreign pipeline while changing the resistance until the foreign pipeline is reverted to the cathodic protection condition or natural potential on a pipeline without cathodic protection. This process is shown in Fig. 18.

The key advantages of a resistance bond over the other mitigation methods are:

- Comparatively cheaper installation.
- Easy to regulate if stray current quantity changes.
- Large current capacity.

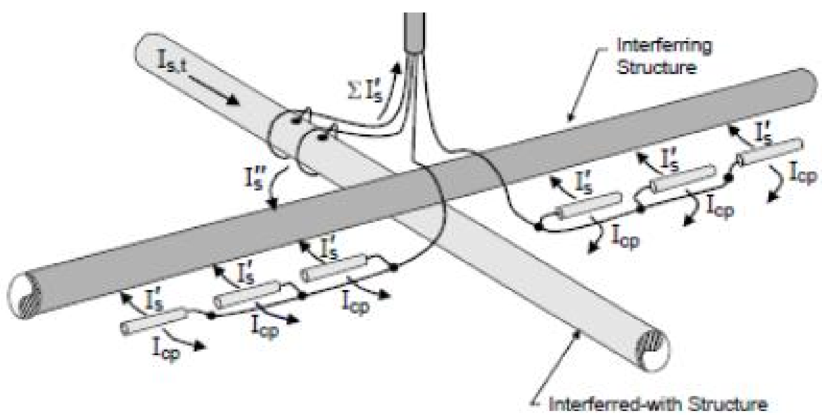


**Fig. 17. Interference prevention using sacrificial anodes at the point of the stray currentrelease [8]**

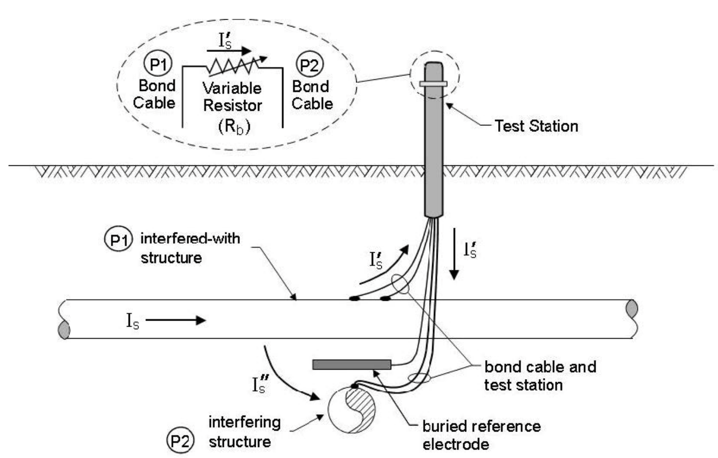


**Fig. 18. Mitigation of Interference by the use of a resistance bond [8]**

### 3.4.6 Use of coating as a mitigation technique

The application of the coating is a means of increasing the resistivity of the SC route, thereby minimising the SC level [21]. As a specific technique, the coating should be applied at pick-up points. If the discharge position is coated, there will likely be corrosion impairment arising from high discharge current density at a break in the coating. This approach is easily applied to a new pipeline where a good quality coating can be utilised at positions where SC pick-up is expected, but it could be impracticable in existing pipelines.

## 4. CONCLUSION

This work considers the strategies for the alleviation of interferences caused by stray currents on impressed current cathodic protection pipeline carrying liquefied gas. The stray current alters cathodic protection by shifting its potential from the designated negative value, and hence expose the pipeline to corrosion. A model for the stray current was developed and then solved in MATLAB. A stray current of 0.74 mA was obtained, with parametric simulation indicating a rise in stray current as anode current output rises. However, the effect of the distance of foreign pipeline from the ground bed shows an inverse relationship. Which is attributed to the resistive nature of the soil. Two methods were proposed to mitigate this negative effect of stray current, the source removal or source output reduction and increasing depth of the buried pipeline, with the formal option promising to be more practicable in the case when the interfering pipeline is newly installed.

This work presents the techniques for mitigating against the interference on impressed current cathodic protection (ICCP) systems. First, a mathematical model of stray current (SC) interference on ICCP systems in a typical pipeline was developed. This model was solved in MATLAB, with key results indicating 0.74 mA of SC. Parametric simulation of some parameters show a rise in SC for an increasing anode current output, while the effect of foreign pipeline distance from the ground bed indicates an inverse relationship with SC, this was identified to be a result of the resistivity of the soil. Mitigation options against SC interference proposed in this research include source removal or output current reduction and increasing distance of foreign pipeline from the bed. To effectively achieve this, the pipeline should be sufficiently buried over 5 m away far from the ground bed, while the anode current should be operated as low as 3.5 mA, or the interfering source be removed in the case that the interfering pipeline is newly installed.

In order to improve on the cathodic protection of pipelines, the following have been recommended for further research.

- The rate of corrosion due to the influence of SC on ICCP structure should be evaluated, to define the mitigation options provided in work broadly.
- The factors such as quality of coating, and the presence of bacteria may cause microbial induced corrosion, and temperature may be considered in modelling the interference of an SC.
- A general overview of other grades of the pipeline could be extensively considered.

The following highlights are the unique contributions of this research to the bulk of existing knowledge in the open literature, concerning mitigation against cathodic protection interferences arising from stray current in underground structures:

- In this research, two techniques have been proposed to alleviate the effects of stray current in an ICCP. These methods include; source removal or source output reduction and increasing depth of the buried pipeline. These techniques compare well with the well-established techniques such as the use of isolating fittings, installation of metallic shield close to the foreign pipeline, etc..
- It was established in this research that a stray current as low as 0.74mA could be achieved at an anode current output of 3.5A and pipeline buried at a distance of 5m below the ground bed.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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