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# Effect of Stray Currents on Underground Pipelines within the Niger Delta Region

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**Abstract**
This study was undertaken to determine the effects of stray currents on underground pipelines within the Niger Delta area. Two gas pipelines were selected for this experiment to investigate the presence of stray currents. The Stationary data logger and the Close Interval Potential Survey tool were used in measuring dynamic stray currents and static stray currents respectively. The sections on the pipelines for survey were selected based on their proximity to possible sources of stray currents. Three sections were surveyed for the first pipeline and two sections for the second pipeline. On survey of the pipelines, significant amount of stray current were detected, sufficient enough to cause corrosion on the pipelines. Furthermore, the effects of the stray current on the pipeline due to weight loss and errors in pipe to soil potential readings were determined. Finally, the sources of the stray currents were investigated and suitable control measures proffered in a bid to protecting the pipelines.
**Keywords:** Niger Delta, corrosion, direct current, stray current, cathodic protection.

## 1. Introduction

The Niger Delta area is a very densely populated region. It is located at an elevation of 96 meters above sea level with coordinates $4^0$49’60”N and $6^0$0’0’E in Degree Minutes Second (DMS) or 4.83333 and 6 in decimal degrees. The Niger delta extends over 70,000 km² and makes up 7.5% of Nigeria’s total land mass (NNPC, 1983). The area accommodates over 20 million people and 40 different ethnic groups (Pagaebi, 2014). It consists of present day Bayelsa, Delta, Rivers, Abia, Akwa-Ibom, Cross River, Edo, Imo and Ondo States.

Oil spills are common occurrences in the Niger Delta area, they occur due to a number of causes including corrosion of pipelines and tankers (accounting for 50% of all spills), sabotage (28%), and oil production operations (21%), with 1% of the spills being accounted for by inadequate or non-functional production equipment, (NNPC, 1983). The largest contributor to the oil spills is the rupturing or leakage of production infrastructures that are old and lack regular inspection and maintenance.

The problem of electrolytic corrosion caused by stray currents is the subject of an increasing number of scientific publications. It is one of the more important present day corrosion problems. Thus, it also is an economic and social problem. The fact that stray currents can indirectly cause a significant ecological hazard is being more fully appreciated (Darowicki and Zakowski, 2000).

Stray currents are major agents of electrolytic corrosion of pipelines, (Richard & Bonds, 1997). They are direct currents flowing through the earth from a source not related to the pipeline being affected as shown in figure 1.1. It is important to note that for stray currents to cause corrosion, they must flow onto the pipeline in one area as shown in figure 1.3, travel along the pipeline to some other area or areas where they then leave the pipe (with resulting corrosion) to reenter the earth and complete the circuit to their ultimate destination. The amount of metal lost from corrosion is directly proportional to the amount of current discharged from the affected pipeline, (Richard & Bonds, 1997). Stray currents can impact the ability to protect a pipeline or other buried metallic structure from corrosion. Stray currents are particularly destructive at the location the current leaves the pipeline; the area of exit of the stray currents creates a localized anodic area on the pipeline which can overcome the cathodic protection applied. Often these areas are in close proximity to the generator of the stray currents or at a defect in the coating or at a crossing of lines.

## 2. Literature review

Stray current is one of the most important present day corrosion problems. The fact that stray currents can indirectly cause significant ecological hazard is being more fully appreciated.

Researches on stray currents have been widely reported in various publications but little emphasis on pipelines laid around the equator which are also prone to stray current due to errors in pipe to soil potential readings caused by the telluric effects of the sun.

Bonds (1997) investigated the effects of stray currents on ductile iron pipes. This study involved rectifiers and anodes located close and far away from the pipelines. All investigations indicated that the amount of influence by the stray currents on the Ductile Iron pipes was negligible for cases were rectifiers and anodes were located far away from the pipelines. For installations located close to the pipelines, the investigations show that the pipelines were influenced by factors such as rectifier output, soil resistivity, diameter of the respective pipelines, condition of the pipeline coating etc.. The most significant part of this study was the recommendation of rubber gasket joints and polyethylene encasement in deterring stray currents from Ductile Iron pipelines.

Darowicki and Zakowski (2000) presented a paper on methods of evaluating corrosion hazards caused by stray currents to metal structures containing aggressive media. This study described the interaction of stray currents; it suggests possibilities of investigating potentials in the time-frequency domain with the use of most recent mathematical tools. In this way obtaining data is expected on electrode processes taking place on the surface of metal structures endangered by the harmful interaction of stray currents.

Darowicki and Zakowski (2001) presented a new method using Short Time Fourier Transformation (STFT) in detecting stray currents. This particular kind of signal analysis makes the determination of changes of the spectral power density of a signal (e.g. structure to electrolyte potential) in function of time possible. In the paper the results of joint time-frequency analysis of the potential of pipeline in the field of stray currents generated by tram-line were presented. The presented results unambiguously show the possibility of accurate identification of sources of stray currents and its interference on the underground metal construction.

Klean and Davies (2005) presented a paper on the basic principles of cathodic protection, the areas of use and the general factors to be considered in the choice and design of a cathodic protection system. It gave a basic introduction and simple technical data on cathodic protection.

Fagot and Schmitt (2008) developed Elsyca's CatPro® and CPMaster® softwares to assess the influence of stray current on sheet piling structures.

Qingjun and et al. (2011) carried out a research to analyse abnormal variation of pipe-to-soil potentials of an oil transfer pipeline. This research showed that both AC and DC stray currents affect underground pipelines. This study further explained that potential gradients cannot indicate stray current corrosion under all circumstances. O'Flaherty and et al. (2011) carried out an analysis of stray currents induced by cathodic protection on steel-framed masonry structures. This paper presented both experimental and numerical studies into the risk and extent of stray current corrosion in steel-framed masonry structures when subjected to impressed current cathodic protection. The objective was to optimise CP systems so that interference could be minimised without compromising the technical or cost benefits of this method of corrosion control.

Demirel and et al. (2013) carried out a research on telluric effects arising along the cathodically protected natural gas pipeline between Karadeniz Eregli and Duzce. This study was aimed at ascertaining the existence, arising frequency, and magnitude of telluric interference going in and out of the natural gas pipeline between D¨uzce and Karadeniz Ere˘gli in Turkey. The gas pipeline is well coated with polyethylene; it is 60 km long and has a diameter of 40.64cm. In this study, the pipe/ground potential values, electrical currents coming from the anode bed, and soil resistivity values were measured at different times and regions along the pipeline. This study proved that the natural gas pipeline between D¨uzce and K.Ere˘gli included interference currents caused by the magnetic field effect (telluric effects) from time to time and also, the pipeline/ground potential values showed that the aforementioned magnetic field strength changes over short periods.

The present work covered the stray current intensity and distribution on underground pipelines, effects of stray currents on pipelines, and the telluric effect of the sun to errors in pipe to soil potential readings within the Niger Delta region using different stray current measuring tools and mathematical models with MATLAB and Microsoft Excel softwares.

## 3. MATERIALS AND METHOD

An experiment was conducted on two gas pipelines to measure stray currents on underground pipelines within the Niger Delta region. A stationary data logger and a Close Interval Potential Survey tool were the instruments used to measure dynamic and static stray currents respectively. The first pipeline was of 457mm diameter and 1.2km long. This pipeline linked SPDC Imo River Flow Station to NGC Owaza Compressor Station as shown in figure 3.1. The second pipeline was of the same diameter but 4km long. It linked Umudi Intermediate Pigging Station to Alaoji Pressure Reduction and Metering Station. The sections on the pipelines for survey were selected based on their proximity to possible sources of stray currents. Three sections were investigated for stray currents for the first pipeline; the sections consisted of kp 0+000 to kp 0+018; kp 0+255 to kp 0+273; and kp 0+602 to kp 0+620. Two sections were investigated for the second pipeline; the sections consisted of kp 20+570 to kp 20+588 and kp 23+420 to kp 23+438. The experiment was carried out two times daily in both dry and wet seasons in the months of November and May respectively for a period of 4days each. The measurements were done in accordance with test procedures outlined by Nicholson (2010) and Nicholson (2003).

 

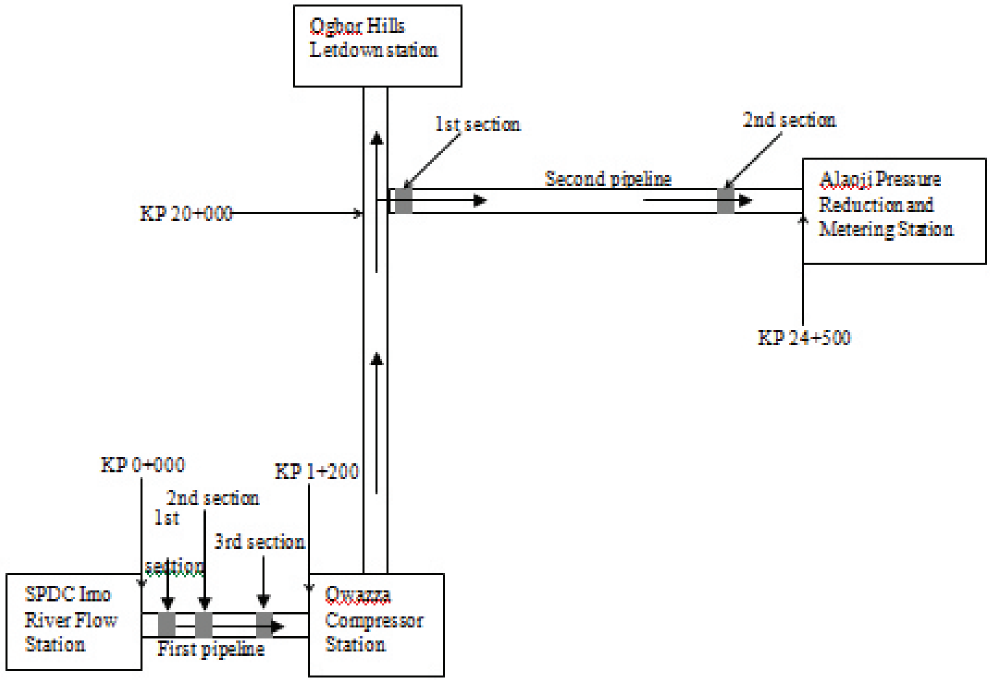


Figure 3.1: General arrangement for pipelines under survey.

**3.2 Test Station**

The test station is a point along the pipeline "right of way" were cables connected to the pipeline are drawn to the surface (above the ground); this is to enable pipe to soil potential measurement. Sacrificial anodes are also located at this point for temporary cathodic protection or stray current mitigation cases. The number of test stations located on a pipeline are dependent on the risk of possible stray current influence. The first pipeline surveyed had more than one test station within one kilometer considering the multiple pipeline crossings from the Imo River Flow Station. The second pipeline had one test station to one kilometer.

**a. Instruments used for measurement**

**i. Stationary data logger (Smart Logger II)**

The stationary data logger is a product of Cathodic Technology Limited Canada, it measures dynamic stray current in millivolts. This instrument has two terminals; one of the terminals is connected to the potential monitoring cable from the pipeline and the other is connected to the soil with a reference electrode.

**ii. Close Interval Potential Survey Instrument (Cath-Tech Hexcorder Millenium GPS)**

The Close Interval Potential Survey Instrument measures static stray currents in millivolts. This instrument also has two terminals; one of the terminals is connected to the potential monitoring cable from the pipeline and the other is connected to the soil with a reference electrode.

**iii. Portable GPS Current interrupter**

This instrument sychronises the GPS enabled Stationary data logger and the Close Interval Potential Survey tool to the rectifier to ensure that the readings of the dynamic stray currents and the static stray currents are taken at the same time over the period of survey. This instrument is a product of Rohrback Cosasco Systems Carlifornia, USA and has an accuracy of ±5 milliseconds.

**3.4 Factors considered in experiment**

Two factors were considered in selecting the sections on the pipeline for survey.

Proximity of the section to:

1. other pipelines or underground steel structures under impressed current cathodic protection.
2. construction sites where welding machines could be in use. Notably, "grounding" welding machines could be a major source of stray current

These two considerations were for potential sources of static and dynamic stray currents respectively.

**a. Procedure for measurement**

1) After the selection of the sections on the pipeline the CIPS equipment and the Stationary data logger were connected to the potential monitoring cable from the underground pipeline at the test station close to the section on the pipeline to be surveyed.

2) The Current Interrupter was then initiated to synchronize all measuring equipment (CIPS equipment and the

 

stationary data logger) to the potential source of static stray current (rectifier) to ensure that the measurements were taken at the same time.
3) Lastly, the pipe to soil potential readings were taken by walking down the line with the CIPS equipment connected to the test station and the surrounding soil with a trailing wire.

### 3.5 Correcting CIPS for stray currents

Close interval potential survey (CIPS) is the backbone of pipeline integrity, because it determines the effectiveness of the cathodic protection system which provides protection against external corrosion. CIPS is widely used to monitor the level of cathodic protection on the pipeline. The goal of the survey is to measure the instant off (rectifier off) potential, which minimizes any effect from the other resistances in the circuit. The difference between the on potential and the instant off is called the IR drop. When dynamic stray or telluric currents influence CIPS survey results, accurate interpretation of the results may be difficult if not impossible. Fluctuation of the pipe-to-soil potential due to dynamic stray or telluric current makes it difficult for the corrosion engineer to validate the integrity of the cathodic protection system protecting a valuable asset (Nicholson, 2007).

The correction of CIPS data was done in accordance with the procedure outlined in a paper on Stray Current Detection and Correction (Nicholson, 2010).

Through using the GPS synchronized data from CIPS and the stationary data logger, the CIPS data was corrected by removing the dynamic stray current effects. This gave a more accurate pipe to soil reading as it removes the influence by external interference. A correction factor was calculated from the stationary logger data that was then applied to the CIPS data. The on and the off values were calculated separately. The correction factor was calculated by finding the average of all the day's entries for the logger, then finding the difference between each reading and the average. For each CIPS reading, the correction factor from the logger data was added or subtracted as necessary. The on and off readings had different correction factors and it was ensured that the readings from the measuring instruments were taken at the same time.

$$CF = \frac{\sum(SDL)}{n(SDL)} \qquad (1)$$

$$D = CIPS - CF \qquad (2)$$

$$correct\ CIPS = CIPS - D \qquad (3)$$

Where
SDL = Stationary data logger values
D = Deviation
CF = Correction Factor

### 3.7 Data Analysis

The static stray current data from the CIPS equipment were presented as voltage differences at Rectifier On/Instant OFF with time. For the dynamic stray current including telluric interference the data from the GPS stationary data logger were also presented as voltage differences at Rectifier On/Instant OFF with time.

For the static stray current, the voltage differences at Rectifier on and Rectifier off were plotted against time to get the voltage difference distribution with time and the result is that, if there is no stray current interference, there should not be any difference between the on and off readings. Where there is a current pickup point, the pipe will show an on reading higher than the off. Where there is a current discharge point, the on readings will go below the off readings (Nicholson, 2010).

For the dynamic stray current, the voltage differences at Rectifier on and Rectifier off were also plotted against time to get the voltage difference distribution with time. From the plot if there are spikes in the voltage during likely work period, the grounding system of DC welding machines used for fabrication/construction works should be checked, when the readings seem to be random, sunspot activities (telluric interference) should be investigated. Further investigation for the source of the stray currents can be done with the cooperation of other potential parties. Loggers can be set out to monitor for longer periods to see if there are any changes to the level of activity during overnight periods or on weekends.

## 4. Result and discussion

### 4.1 Presentation of data for the first pipeline (all measurements in negative millivolts)

Three sections were selected for investigation for the presence of stray current for the first pipeline. The sections weere: Section 1 (kp0+000 to kp0+018), Section 2 (kp0+255 to kp0+273), and Section 3 (kp0+602 to kp)+620). The measurements were taken two times daily (afternoon and evening) for a period of four days during the dry and wet seasons.

#### 4.1.1 Results of stray current measurement for the first pipeline

Table 4.1. Section 1(kp0+000 to kp 0+018); Day 1 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 743 | 750 | 728 | 761 | -22.3 | 18.4 | 765.3 | 731.6 | 762 | 764 |
| 750 | 758 | 726 | 751 | -24.3 | 8.4 | 774.3 | 749.6 | 745 | 756 |
| 732 | 757 | 745 | 745 | -5.3 | 2.4 | 737.3 | 754.6 | 771 | 781 |
| 701 | 730 | 763 | 723 | 12.7 | -19.6 | 688.3 | 717.3 | 734 | 750 |
| 743 | 752 | 762 | 732 | 11.7 | -10.6 | 731.3 | 762.6 | 745 | 759 |
| 734 | 840 | 757 | 741 | 6.7 | -1.6 | 727.3 | 841.6 | 776 | 777 |
| 724 | 730 | 751 | 742 | 0.7 | -0.6 | 723.3 | 730.6 | 756 | 760 |
| 735 | 740 | 768 | 749 | 17.7 | 6.4 | 717.3 | 733.6 | 783 | 784 |
| 750 | 757 | 762 | 749 | 11.7 | 6.4 | 738.3 | 750.6 | 756 | 763 |
| 723 | 749 | 741 | 733 | -9.3 | -9.6 | 732.3 | 758.6 | 761 | 766 |

Table 4.2. Section 1 (kp0+000 to 0+018); Day 1 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 753 | 762 | 756 | 762 |
| 757 | 761 | 765 | 770 |
| 759 | 760 | 745 | 757 |
| 762 | 777 | 768 | 781 |
| 770 | 781 | 738 | 746 |
| 734 | 750 | 753 | 769 |
| 745 | 748 | 745 | 752 |
| 749 | 761 | 758 | 764 |
| 750 | 782 | 759 | 760 |
| 753 | 754 | 754 | 770 |

Table 4.3. Section 1 (kp0+000 to 0+018); Day 2 for dry season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 777 | 790 | 761 | 767 |
| 745 | 749 | 743 | 750 |
| 753 | 761 | 749 | 753 |
| 746 | 750 | 761 | 772 |
| 771 | 772 | 771 | 782 |
| 777 | 781 | 765 | 783 |
| 766 | 773 | 768 | 783 |
| 767 | 780 | 746 | 752 |
| 781 | 783 | 762 | 765 |
| 782 | 791 | 772 | 779 |

Table 4.4. Section 1 (kp0+000 to 0+018); Day 2 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 745 | 750 | 745 | 751 |
| 765 | 766 | 756 | 762 |
| 744 | 750 | 748 | 755 |
| 755 | 764 | 745 | 760 |
| 762 | 771 | 762 | 763 |
| 765 | 772 | 747 | 754 |
| 765 | 769 | 752 | 757 |
| 770 | 779 | 750 | 757 |
| 754 | 760 | 764 | 768 |
| 756 | 760 | 749 | 755 |

 

Table 4.5. Section 1(kp0+000 to kp 0+018); Day 3 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 744 | 750 | 730 | 760 | -22 | 7.7 | 766 | 742.3 | 723 | 730 |
| 754 | 785 | 731 | 750 | -21 | -2.3 | 775 | 787.3 | 731 | 737 |
| 762 | 794 | 743 | 745 | -9 | -7.3 | 771 | 801.3 | 745 | 750 |
| 783 | 793 | 761 | 724 | 9 | -28.3 | 774 | 784 | 770 | 772 |
| 760 | 783 | 762 | 763 | 10 | 10.7 | 750 | 772.3 | 762 | 770 |
| 781 | 790 | 756 | 760 | 4 | 7.7 | 777 | 782.3 | 755 | 761 |
| 800 | 801 | 750 | 755 | -2 | 2.7 | 802 | 798.3 | 782 | 785 |
| 770 | 782 | 764 | 767 | 12 | 14.7 | 758 | 767.3 | 734 | 740 |
| 800 | 811 | 782 | 749 | 30 | -3.3 | 770 | 814.3 | 756 | 761 |
| 781 | 789 | 741 | 750 | -11 | -2.3 | 792 | 791.3 | 757 | 760 |

Table 4.6. Section 1 (kp0+000 to kp 0+018); Day 3 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 755 | 760 | 746 | 752 |
| 754 | 760 | 748 | 753 |
| 754 | 767 | 751 | 760 |
| 765 | 771 | 755 | 758 |
| 760 | 771 | 760 | 763 |
| 765 | 790 | 762 | 764 |
| 758 | 760 | 763 | 767 |
| 748 | 750 | 763 | 764 |
| 783 | 785 | 754 | 761 |
| 754 | 760 | 746 | 759 |

Table 4.7. Section 1(kp0+000 to kp 0+018); Day 4 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 733 | 753 | 740 | 755 | -13.7 | -1.5 | 746.7 | 754.5 | 761 | 777 |
| 756 | 757 | 755 | 751 | 1.3 | -5.5 | 754.7 | 762.5 | 753 | 760 |
| 732 | 780 | 743 | 745 | -10.7 | -11.5 | 742.7 | 791.5 | 756 | 763 |
| 745 | 783 | 757 | 730 | 3.3 | -26.5 | 741.7 | 779.7 | 745 | 749 |
| 760 | 783 | 758 | 769 | 4.3 | 12.5 | 755.7 | 770.5 | 756 | 759 |
| 782 | 791 | 756 | 760 | 2.3 | 3.5 | 779.7 | 787.5 | 784 | 785 |
| 801 | 790 | 751 | 756 | -2.7 | -0.5 | 803.7 | 790.5 | 745 | 754 |
| 777 | 782 | 765 | 766 | 11.3 | 9.5 | 765.7 | 772.5 | 734 | 754 |
| 790 | 810 | 770 | 782 | 16.3 | 25.5 | 773.7 | 784.5 | 756 | 757 |
| 781 | 788 | 742 | 751 | -11.7 | -5.5 | 792.7 | 793.5 | 757 | 767 |

Table 4.8. Section 1 (kp0+000 to kp 0+018); Day 4 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 737 | 750 | 743 | 750 |
| 745 | 757 | 745 | 750 |
| 745 | 753 | 752 | 757 |
| 754 | 760 | 745 | 752 |
| 756 | 760 | 759 | 765 |
| 760 | 762 | 761 | 763 |
| 754 | 769 | 762 | 769 |
| 746 | 750 | 743 | 750 |
| 751 | 753 | 756 | 760 |
| 753 | 754 | 756 | 763 |

**4.1.2 Discussion on section 1 of the first pipeline**

The results for section 1 for both the dry and wet seasons show that the on readings (readings taken while the rectifier was on) were below the off readings (readings taken while the rectifier was off) as shown in all the table readings for this section implying a current discharge section. Furthermore, the readings for the measurements done in the afternoons as shown in all the tables for readings taken during the day for the dry season indicated presence of dynamic stray currents from construction sites where welding machines were in use. For the evenings, there was no presence of dynamic stray current because no welding activity was going on within the area.

Table 4.9. Section 2 (kp 0+255 to kp 0+273); Day 1for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 776 | 760 | 762 | 751 | 9.1 | 5 | 766.9 | 755 | 765 | 760 |
| 765 | 760 | 756 | 749 | 3.1 | 3 | 761.9 | 757 | 756 | 751 |
| 756 | 743 | 754 | 749 | 1.1 | 3 | 754.9 | 740 | 771 | 766 |
| 765 | 755 | 761 | 755 | 8.1 | 9 | 756.9 | 746.9 | 745 | 741 |
| 785 | 770 | 745 | 738 | -7.9 | -8 | 792.9 | 778 | 746 | 742 |
| 765 | 759 | 749 | 740 | -3.9 | -6 | 768.9 | 765 | 756 | 754 |
| 754 | 750 | 748 | 741 | -4.9 | -5 | 758.9 | 755 | 759 | 756 |
| 765 | 760 | 750 | 745 | -2.9 | -1 | 767.9 | 761 | 770 | 763 |
| 769 | 760 | 751 | 742 | -1.9 | -4 | 770.9 | 764 | 765 | 752 |
| 753 | 751 | 753 | 750 | 0.1 | 4 | 752.9 | 747 | 755 | 751 |

Table 4.10. Section 2 (kp 0+255 to kp 0+273); Day 1for wet season

| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
|---|---|---|---|
| 754 | 750 | 756 | 751 |
| 756 | 751 | 765 | 762 |
| 764 | 759 | 756 | 751 |
| 754 | 749 | 768 | 761 |
| 759 | 749 | 777 | 765 |
| 746 | 736 | 764 | 758 |
| 754 | 750 | 754 | 749 |
| 749 | 740 | 759 | 750 |
| 751 | 745 | 760 | 754 |
| 752 | 748 | 754 | 746 |

Table 4.11. Section 2 (kp 0+255 to kp 0+273); Day 2 for dry season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 760 | 754 | 745 | 741 |
| 755 | 750 | 756 | 750 |
| 750 | 745 | 746 | 739 |
| 758 | 751 | 755 | 751 |
| 762 | 756 | 761 | 755 |
| 761 | 758 | 765 | 754 |
| 751 | 743 | 768 | 755 |
| 762 | 755 | 740 | 738 |
| 765 | 760 | 743 | 740 |
| 760 | 754 | 766 | 756 |

Table 4.12. Section 2 (kp 0+255 to kp 0+273); Day 2 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 745 | 740 | 769 | 760 |
| 755 | 752 | 765 | 761 |
| 746 | 739 | 758 | 752 |
| 754 | 748 | 765 | 760 |
| 756 | 754 | 758 | 755 |
| 751 | 746 | 770 | 761 |
| 752 | 745 | 753 | 745 |
| 753 | 746 | 750 | 745 |
| 758 | 750 | 761 | 752 |
| 756 | 751 | 750 | 745 |

Table 4.13. Section 2 (kp 0+255 to kp 0+273) Day 3 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 755 | 751 | 732 | 730 | -18.8 | -12.9 | 773.8 | 763.9 | 754 | 751 |
| 754 | 750 | 731 | 729 | -19.8 | -13.9 | 773.8 | 763.9 | 756 | 749 |
| 761 | 758 | 745 | 735 | -5.8 | -7.9 | 766.8 | 765.9 | 748 | 741 |
| 754 | 751 | 759 | 746 | 8.2 | 3.1 | 745.8 | 742.8 | 756 | 749 |
| 760 | 745 | 762 | 755 | 11.2 | 12.1 | 748.8 | 732.9 | 761 | 752 |
| 770 | 761 | 758 | 751 | 7.2 | 8.1 | 762.8 | 752.9 | 751 | 741 |
| 764 | 753 | 751 | 739 | 0.2 | -3.9 | 763.8 | 756.9 | 743 | 738 |
| 765 | 760 | 764 | 755 | 13.2 | 12.1 | 751.8 | 747.9 | 744 | 738 |
| 768 | 762 | 765 | 755 | 14.2 | 12.1 | 753.8 | 749.9 | 749 | 739 |
| 770 | 762 | 741 | 734 | -9.8 | -8.9 | 779.8 | 770.9 | 752 | 745 |

Table 4.14. Section 2 (kp 0+255 to kp 0+273); Day 3 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 755 | 750 | 747 | 739 |
| 754 | 750 | 748 | 740 |
| 753 | 749 | 768 | 761 |
| 745 | 741 | 768 | 762 |
| 760 | 755 | 767 | 760 |
| 764 | 759 | 754 | 751 |
| 759 | 749 | 759 | 752 |
| 748 | 744 | 763 | 761 |
| 754 | 750 | 754 | 750 |
| 748 | 742 | 759 | 751 |

Table 4.15. Section 2 (kp 0+255 to kp 0+273) Day 4 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 755 | 750 | 740 | 735 | -7.6 | -5.4 | 762.6 | 755.4 | 761 | 777 |
| 756 | 749 | 755 | 746 | 7.4 | 5.6 | 748.6 | 743.4 | 753 | 760 |
| 746 | 740 | 746 | 743 | -1.6 | 2.6 | 747.6 | 737.4 | 756 | 763 |
| 748 | 741 | 752 | 748 | 4.4 | 7.6 | 743.6 | 736.6 | 745 | 749 |
| 756 | 752 | 754 | 743 | 6.4 | 2.6 | 749.6 | 749.4 | 756 | 759 |
| 759 | 750 | 743 | 737 | -4.6 | -3.4 | 763.6 | 753.4 | 784 | 785 |
| 761 | 755 | 750 | 739 | 2.4 | -1.4 | 758.6 | 756.4 | 745 | 754 |
| 756 | 752 | 743 | 731 | -4.6 | -9.4 | 760.6 | 761.4 | 734 | 754 |
| 756 | 749 | 742 | 734 | -5.6 | -6.4 | 761.6 | 755.4 | 756 | 757 |
| 747 | 739 | 751 | 748 | 3.4 | 7.6 | 743.6 | 731.4 | 757 | 767 |

Table 4.16. Section 2 (kp 0+255 to kp 0+273); Day 4 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 745 | 740 | 765 | 761 |
| 747 | 732 | 761 | 755 |
| 750 | 749 | 755 | 750 |
| 751 | 745 | 758 | 751 |
| 753 | 752 | 754 | 752 |
| 754 | 746 | 761 | 754 |
| 745 | 740 | 763 | 755 |
| 745 | 739 | 756 | 750 |
| 751 | 747 | 765 | 760 |
| 760 | 751 | 763 | 760 |

**4.1.3 Discussions on section 2 of the first pipeline**

The results for section 2 for both the dry and wet seasons show that the on readings were higher than the off readings as shown in all the table readings for this section implying a current pickup section. Furthermore, the readings for the measurements taken in the afternoons for the third and fourth days as shown in Tables 4.25 and 4.29 indicated presence of dynamic stray currents from construction sites where welding machines were in use.

Table 4.17. Section 3 (kp 0+602 to kp 0+620); Day 1 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 770 | 760 | 763 | 755 | 9.4 | 8.9 | 760.6 | 751.1 | 765 | 759 |
| 763 | 759 | 760 | 749 | 6.4 | 2.9 | 756.6 | 756.1 | 754 | 748 |
| 757 | 743 | 754 | 746 | 0.4 | -0.1 | 756.6 | 743.1 | 763 | 757 |
| 765 | 755 | 761 | 755 | 7.4 | 8.9 | 757.6 | 747.6 | 749 | 742 |
| 777 | 767 | 750 | 746 | -3.6 | -0.1 | 780.6 | 767.1 | 746 | 740 |
| 756 | 759 | 745 | 740 | -8.6 | -6.1 | 764.6 | 765.1 | 756 | 748 |
| 756 | 750 | 748 | 741 | -5.6 | -5.1 | 761.6 | 755.1 | 760 | 752 |
| 768 | 766 | 750 | 743 | -3.6 | -3.1 | 771.6 | 769.1 | 770 | 763 |
| 769 | 760 | 752 | 742 | -1.6 | -4.1 | 770.6 | 764.1 | 766 | 752 |
| 754 | 751 | 753 | 744 | -0.6 | -2.1 | 754.6 | 753.1 | 766 | 760 |

 

Table 4.18. Section 3 (kp 0+602 to kp 0+620); Day 1 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 760 | 753 | 755 | 751 |
| 756 | 750 | 765 | 762 |
| 762 | 755 | 756 | 749 |
| 755 | 753 | 765 | 759 |
| 759 | 750 | 777 | 770 |
| 750 | 744 | 764 | 758 |
| 754 | 750 | 750 | 739 |
| 749 | 748 | 759 | 750 |
| 753 | 750 | 760 | 755 |
| 752 | 741 | 759 | 742 |

Table 4.19. Section 3 (kp 0+602 to kp 0+620); Day 2 for dry season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 764 | 754 | 750 | 742 |
| 755 | 747 | 746 | 740 |
| 755 | 745 | 759 | 748 |
| 758 | 746 | 756 | 751 |
| 764 | 750 | 761 | 755 |
| 765 | 758 | 770 | 760 |
| 751 | 743 | 766 | 756 |
| 762 | 757 | 740 | 736 |
| 754 | 749 | 744 | 735 |
| 760 | 754 | 765 | 755 |

Table 4.20. Section 3 (kp 0+602 to kp 0+620); Day 2 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 743 | 740 | 756 | 745 |
| 746 | 739 | 754 | 743 |
| 746 | 740 | 760 | 752 |
| 754 | 751 | 765 | 760 |
| 750 | 742 | 758 | 745 |
| 752 | 739 | 750 | 745 |
| 760 | 755 | 753 | 749 |
| 753 | 749 | 748 | 740 |
| 758 | 750 | 761 | 752 |
| 755 | 751 | 750 | 743 |

Table 4.21. Section 3 (kp 0+602 to kp 0+620)Day 3 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 753 | 748 | 732 | 730 | -18.8 | -12.9 | 771.8 | 760.9 | 759 | 751 |
| 765 | 750 | 731 | 729 | -19.8 | -13.9 | 784.8 | 763.9 | 748 | 739 |
| 761 | 751 | 745 | 735 | -5.8 | -7.9 | 766.8 | 758.9 | 756 | 746 |
| 764 | 750 | 759 | 746 | 8.2 | 3.1 | 755.8 | 741.8 | 760 | 755 |
| 760 | 755 | 762 | 755 | 11.2 | 12.1 | 748.8 | 742.9 | 763 | 755 |
| 770 | 762 | 758 | 751 | 7.2 | 8.1 | 762.8 | 753.9 | 765 | 761 |
| 777 | 770 | 751 | 739 | 0.2 | -3.9 | 776.8 | 773.9 | 743 | 740 |
| 765 | 762 | 764 | 755 | 13.2 | 12.1 | 751.8 | 749.9 | 750 | 743 |
| 768 | 760 | 765 | 755 | 14.2 | 12.1 | 753.8 | 747.9 | 749 | 743 |
| 771 | 762 | 741 | 734 | -9.8 | -8.9 | 780.8 | 770.9 | 753 | 748 |

Table 4.22. Section 3 (kp 0+602 to kp 0+620); Day 3 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 744 | 740 | 750 | 740 |
| 754 | 749 | 748 | 743 |
| 755 | 750 | 765 | 761 |
| 745 | 741 | 767 | 762 |
| 760 | 755 | 768 | 760 |
| 765 | 759 | 750 | 743 |
| 745 | 737 | 759 | 752 |
| 750 | 744 | 750 | 745 |
| 739 | 735 | 754 | 750 |
| 740 | 735 | 757 | 750 |

Table 4.23. Section 3 (kp 0+602 to kp 0+620); Day 4 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 759 | 751 | 740 | 735 | -7.6 | -5.4 | 766.6 | 756.4 | 761 | 777 |
| 755 | 749 | 755 | 746 | 7.4 | 5.6 | 747.6 | 743.4 | 753 | 760 |
| 746 | 738 | 746 | 743 | -1.6 | 2.6 | 747.6 | 735.4 | 756 | 763 |
| 746 | 742 | 752 | 748 | 4.4 | 7.6 | 741.6 | 737.6 | 745 | 749 |
| 760 | 756 | 754 | 743 | 6.4 | 2.6 | 753.6 | 753.4 | 756 | 759 |
| 759 | 755 | 743 | 737 | -4.6 | -3.4 | 763.6 | 758.4 | 784 | 785 |
| 752 | 741 | 750 | 739 | 2.4 | -1.4 | 749.6 | 742.4 | 745 | 754 |
| 756 | 749 | 743 | 731 | -4.6 | -9.4 | 760.6 | 758.4 | 734 | 754 |
| 756 | 745 | 742 | 734 | -5.6 | -6.4 | 761.6 | 751.4 | 756 | 757 |
| 765 | 758 | 751 | 748 | 3.4 | 7.6 | 761.6 | 750.4 | 757 | 767 |

Table 4.24. Section 3 (kp 0+602 to kp 0+620); Day 4 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 750 | 740 | 750 | 743 |
| 744 | 732 | 765 | 750 |
| 750 | 740 | 753 | 745 |
| 746 | 739 | 758 | 751 |
| 753 | 752 | 751 | 743 |
| 754 | 746 | 759 | 751 |
| 763 | 750 | 763 | 746 |
| 766 | 755 | 760 | 755 |
| 768 | 761 | 765 | 760 |
| 760 | 751 | 763 | 760 |

#### 4.1.4 Discussion on section 3 of the first pipeline

The results for section 3 for both the dry and wet seasons show that the on readings were higher than the off readings as shown in all the table readings for this section implying a current pickup section. Furthermore, the readings for the measurements taken in the afternoons for the first and third days as shown in Tables 4.33 and 4.41 indicated presence of dynamic stray currents from construction sites where welding machines were in use.

### 4.2 Presentation of data for the second pipeline (all measurements in negative millivolts)

Two sections were selected for investigation for the presence of stray current for the second pipeline. The sections were: Section 1 (kp20+570 to kp20+588), and Section 2 (kp23+420 to kp23+438). The measurements were also taken two times daily (afternoon and evening) for a period of four days during the dry and wet seasons.

**4.2.1 Results of stray current measurement for the second pipeline**

Table 4.25. Section 1 (kp 20+570 to kp 20+588) Day 1 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 780 | 771 | 546 | 399 | -56.6 | -217.1 | 836.6 | 988.1 | 764 | 753 |
| 760 | 755 | 640 | 657 | 37.4 | 40.9 | 722.6 | 714.1 | 765 | 745 |
| 755 | 750 | 750 | 546 | 147.4 | -70.1 | 607.6 | 820.1 | 743 | 756 |
| 765 | 761 | 649 | 763 | 46.4 | 146.9 | 718.6 | 714.6 | 765 | 742 |
| 782 | 773 | 453 | 647 | -149.6 | 30.9 | 931.6 | 742.1 | 762 | 742 |
| 765 | 761 | 747 | 646 | 144.4 | 29.9 | 620.6 | 731.1 | 762 | 748 |
| 792 | 781 | 648 | 342 | 45.4 | -274.1 | 746.6 | 1055.1 | 756 | 756 |
| 745 | 739 | 300 | 658 | -302.6 | 41.9 | 1047.6 | 697.1 | 771 | 761 |
| 765 | 756 | 747 | 759 | 144.4 | 142.9 | 620.6 | 613.1 | 766 | 765 |
| 777 | 747 | 546 | 744 | -56.6 | 127.9 | 833.6 | 619.1 | 763 | 746 |

Table 4.26. Section 1 (kp 20+570 to kp 20+588); Day 1 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 763 | 753 | 734 | 730 |
| 757 | 756 | 765 | 755 |
| 761 | 755 | 765 | 755 |
| 756 | 748 | 754 | 751 |
| 759 | 763 | 760 | 755 |
| 750 | 748 | 764 | 762 |
| 745 | 740 | 755 | 749 |
| 749 | 748 | 745 | 739 |
| 756 | 750 | 761 | 755 |
| 752 | 741 | 759 | 742 |

Table 4.27. Section 1 (kp 20+570 to kp 20+588) day 2 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 756 | 751 | 654 | 644 | 83.5 | -48.3 | 672.5 | 799.3 | 756 | 764 |
| 756 | 750 | 300 | 764 | -270.5 | 71.7 | 1026.5 | 678.3 | 774 | 764 |
| 743 | 740 | 250 | 478 | -320.5 | -214.3 | 1063.5 | 954.3 | 756 | 756 |
| 761 | 755 | 450 | 748 | -120.5 | 55.7 | 881.5 | 875.5 | 764 | 751 |
| 754 | 747 | 567 | 658 | -3.5 | -34.3 | 757.5 | 781.3 | 791 | 755 |
| 759 | 751 | 634 | 746 | 63.5 | 53.7 | 695.5 | 697.3 | 746 | 761 |
| 766 | 760 | 764 | 647 | 193.5 | -45.3 | 572.5 | 805.3 | 782 | 761 |
| 769 | 761 | 729 | 765 | 158.5 | 72.7 | 610.5 | 688.3 | 745 | 736 |
| 756 | 745 | 613 | 739 | 42.5 | 46.7 | 713.5 | 698.3 | 777 | 745 |

 

Table 4.28. Section 1 (kp 20+570 to kp 20+588); Day 2 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT | CIPS RECT | CIPS RECT |
| 781 | 765 | 756 | 745 |
| 782 | 771 | 765 | 754 |
| 770 | 763 | 760 | 752 |
| 753 | 750 | 768 | 760 |
| 746 | 742 | 744 | 735 |
| 782 | 774 | 750 | 745 |
| 756 | 751 | 753 | 749 |
| 764 | 760 | 756 | 740 |
| 764 | 750 | 761 | 752 |
| 756 | 751 | 748 | 745 |

Table 4.29. Section 1 (kp 20+570 to kp 20+588); Day 3 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 751 | 748 | 644 | 546 | 93.6 | 0.2 | 657.4 | 747.8 | 765 | 753 |
| 764 | 750 | 763 | 627 | 212.6 | 81.2 | 551.4 | 668.8 | 764 | 741 |
| 759 | 751 | 647 | 342 | 96.6 | -203.8 | 662.4 | 954.8 | 756 | 746 |
| 742 | 752 | 321 | 455 | -229.4 | -90.8 | 971.4 | 981.4 | 763 | 755 |
| 748 | 755 | 647 | 566 | 96.6 | 20.2 | 651.4 | 734.8 | 763 | 756 |
| 764 | 762 | 455 | 362 | -95.4 | -183.8 | 859.4 | 945.8 | 777 | 761 |
| 777 | 771 | 674 | 645 | 123.6 | 99.2 | 653.4 | 671.8 | 755 | 745 |
| 765 | 762 | 754 | 748 | 203.6 | 202.2 | 561.4 | 559.8 | 751 | 762 |
| 768 | 763 | 255 | 624 | -295.4 | 78.2 | 1063.4 | 684.8 | 749 | 743 |
| 772 | 762 | 344 | 543 | -206.4 | -2.8 | 978.4 | 764.8 | 753 | 760 |

Table 4.30. Section 1 (kp 20+570 to kp 20+588); Day 3 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 785 | 775 | 765 | 750 |
| 764 | 757 | 783 | 760 |
| 754 | 751 | 742 | 735 |
| 771 | 765 | 756 | 745 |
| 763 | 760 | 777 | 760 |
| 756 | 749 | 750 | 743 |
| 768 | 761 | 760 | 753 |
| 764 | 753 | 756 | 745 |
| 739 | 735 | 754 | 749 |
| 750 | 736 | 743 | 738 |

 

Table 4.31. Section 1 (kp 20+570 to kp 20+588); Day 4 for dry season

| AFTERNOON | | EVENING | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT | DATA LOGGER RECT | ON DEVIATION | OFF DEVIATION | CORRECT RECT | CORRECT RECT |
| 735 | 754 | 754 | 743 | 555 | 355 | -2.8 | -301.1 | 756.8 | 1044.1 |
| 765 | 749 | 744 | 731 | 625 | 637 | 67.2 | -19.1 | 676.8 | 750.1 |
| 765 | 764 | 756 | 752 | 647 | 637 | 89.2 | -19.1 | 666.8 | 771.1 |
| 743 | 751 | 742 | 735 | 321 | 667 | -236.8 | 10.9 | 978.8 | 971.8 |
| 765 | 756 | 761 | 755 | 647 | 647 | 89.2 | -9.1 | 671.8 | 764.1 |
| 756 | 743 | 746 | 735 | 355 | 763 | -202.8 | 106.9 | 948.8 | 628.1 |
| 752 | 741 | 777 | 761 | 674 | 838 | 116.2 | 181.9 | 660.8 | 579.1 |
| 756 | 761 | 765 | 760 | 673 | 737 | 115.2 | 80.9 | 649.8 | 679.1 |
| 761 | 745 | 756 | 751 | 737 | 737 | 179.2 | 80.9 | 576.8 | 670.1 |
| 765 | 745 | 772 | 770 | 344 | 543 | -213.8 | -113.1 | 985.8 | 883.1 |

Table 4.32. Section 1 (kp 20+570 to kp 20+588); Day 4 for wet season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT | CIPS RECT | DATA LOGGER | DATA LOGGER | ON DEVIAT | OFF DEVIAT | CORRECT | CORRECT | CIPS RECT | CIPS RECT |
| 765 | 760 | 657 | 684 | 49.8 | 151.4 | 715.2 | 608.6 | 751 | 745 |
| 747 | 740 | 765 | 456 | 157.8 | -76.6 | 589.2 | 816.6 | 765 | 749 |
| 756 | 751 | 345 | 435 | -262.2 | -97.6 | 1018.2 | 848.6 | 759 | 745 |
| 768 | 760 | 657 | 564 | 49.8 | 31.4 | 718.2 | 710.2 | 768 | 765 |
| 756 | 750 | 748 | 645 | 140.8 | 112.4 | 615.2 | 637.6 | 771 | 758 |
| 765 | 761 | 657 | 564 | 49.8 | 31.4 | 715.2 | 729.6 | 759 | 750 |
| 777 | 755 | 456 | 646 | -151.2 | 113.4 | 928.2 | 641.6 | 763 | 746 |
| 760 | 751 | 673 | 444 | 65.8 | -88.6 | 694.2 | 839.6 | 763 | 755 |
| 756 | 751 | 737 | 345 | 129.8 | -187.6 | 626.2 | 938.6 | 765 | 759 |
| 782 | 770 | 377 | 543 | -230.2 | 10.4 | 1012.2 | 759.6 | 756 | 755 |

Table 4.33. Section 2 (kp 23+420 to kp 23+438); Day 1for dry season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 760 | 771 | 745 | 752 |
| 756 | 765 | 768 | 771 |
| 765 | 771 | 768 | 773 |
| 756 | 769 | 784 | 791 |
| 756 | 762 | 764 | 772 |
| 765 | 771 | 762 | 771 |
| 782 | 789 | 756 | 760 |
| 756 | 760 | 765 | 768 |
| 768 | 791 | 764 | 768 |
| 748 | 752 | 763 | 770 |

Table 4.34. Section 2 (kp 23+420 to kp 23+438); Day 1 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 784 | 791 | 756 | 761 |
| 757 | 763 | 765 | 774 |
| 755 | 768 | 783 | 790 |
| 756 | 766 | 765 | 770 |
| 768 | 775 | 760 | 771 |
| 750 | 761 | 764 | 774 |
| 745 | 758 | 765 | 774 |
| 749 | 756 | 745 | 759 |
| 789 | 792 | 780 | 782 |
| 752 | 763 | 759 | 765 |

Table 4.35. Section 2 (kp 23+420 to kp 23+438); Day 2 for dry season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 761 | 768 | 756 | 764 |
| 751 | 755 | 774 | 780 |
| 763 | 771 | 762 | 770 |
| 761 | 768 | 756 | 762 |
| 764 | 769 | 782 | 791 |
| 755 | 762 | 756 | 761 |
| 764 | 771 | 763 | 769 |
| 758 | 770 | 750 | 763 |
| 759 | 771 | 760 | 768 |
| 748 | 759 | 765 | 769 |

Table 4.36. Section 2 (kp 23+420 to kp 23+438); Day 2 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 785 | 792 | 765 | 772 |
| 784 | 788 | 784 | 790 |
| 770 | 781 | 760 | 764 |
| 753 | 760 | 783 | 792 |
| 756 | 762 | 744 | 755 |
| 782 | 791 | 750 | 762 |
| 756 | 765 | 765 | 769 |
| 785 | 789 | 764 | 769 |
| 764 | 770 | 761 | 768 |
| 784 | 791 | 748 | 750 |

 

Table 4.37. Section 2 (kp 23+420 to kp 23+438); Day 3 for dry season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 753 | 761 | 765 | 771 |
| 764 | 773 | 764 | 769 |
| 759 | 761 | 756 | 761 |
| 762 | 771 | 782 | 791 |
| 756 | 761 | 763 | 772 |
| 764 | 769 | 764 | 769 |
| 777 | 781 | 755 | 761 |
| 784 | 789 | 751 | 760 |
| 756 | 761 | 765 | 743 |
| 772 | 774 | 753 | 760 |

Table 4.38. Section 2 (kp 23+420 to kp 23+438); Day 3 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 785 | 790 | 765 | 771 |
| 777 | 801 | 783 | 792 |
| 765 | 775 | 750 | 765 |
| 781 | 784 | 768 | 786 |
| 745 | 765 | 777 | 784 |
| 765 | 770 | 750 | 765 |
| 768 | 771 | 765 | 778 |
| 764 | 770 | 756 | 768 |
| 790 | 804 | 765 | 768 |
| 750 | 754 | 743 | 768 |

 

Table 4.39. Section 2 (kp 23+420 to kp 23+438); Day 4 for dry season

| AFTERNOON | | | | | | | | EVENING | |
|---|---|---|---|---|---|---|---|---|---|
| CIPS RECT ON | CIPS RECT OFF | DATA LOGGER RECT ON | DATA LOGGER RECT OFF | ON DEVIATION | OFF DEVIATION | CORRECT RECT ON | CORRECT RECT OFF | CIPS RECT ON | CIPS RECT OFF |
| 764 | 769 | 655 | 673 | 131.1 | 140.8 | 632.9 | 628.2 | 756 | 762 |
| 759 | 768 | 674 | 454 | 150.1 | -78.2 | 608.9 | 846.2 | 744 | 756 |
| 765 | 769 | 455 | 373 | -68.9 | -159.2 | 833.9 | 928.2 | 756 | 762 |
| 756 | 761 | 277 | 546 | -246.9 | 13.8 | 1002.9 | 1007.9 | 765 | 771 |
| 768 | 775 | 647 | 648 | 123.1 | 115.8 | 644.9 | 659.2 | 761 | 768 |
| 789 | 793 | 455 | 546 | -68.9 | 13.8 | 857.9 | 779.2 | 746 | 756 |
| 765 | 780 | 645 | 234 | 121.1 | -298.2 | 643.9 | 1078.2 | 782 | 789 |
| 765 | 775 | 754 | 647 | 230.1 | 114.8 | 534.9 | 660.2 | 765 | 770 |
| 789 | 791 | 333 | 658 | -190.9 | 125.8 | 979.9 | 665.2 | 756 | 762 |
| 772 | 783 | 344 | 543 | -179.9 | 10.8 | 951.9 | 772.2 | 772 | 779 |

Table 4.40. Section 2 (kp 23+420 to kp 23+438); Day 4 for wet season

| AFTERNOON | | EVENING | |
|---|---|---|---|
| CIPS RECT | CIPS RECT | CIPS RECT | CIPS RECT |
| 765 | 771 | 753 | 762 |
| 784 | 792 | 758 | 772 |
| 789 | 812 | 759 | 763 |
| 754 | 765 | 768 | 781 |
| 763 | 770 | 765 | 768 |
| 765 | 771 | 756 | 765 |
| 777 | 780 | 763 | 785 |
| 764 | 781 | 762 | 775 |
| 756 | 764 | 743 | 767 |
| 789 | 790 | 756 | 768 |

**4.2.2 Discussion on the two sections of the second pipeline**

The random readings for the second pipeline show telluric effect of the sun due to sunspot activities on the earth magnetic field. This can create an error in the pipe to soil potential readings by making the pipeline appear to have better or worse cathodic protection than it actually has.

**4.3 Data analysis**

This study sought to investigate the amount of current entering or leaving the pipe surface to enable it compute the rate of metal loss (corrosion rate) of the pipeline

**4.3.1 Total current entering or leaving the pipe surface**

$$\Delta\varphi = 0.734\rho j \qquad (4)$$

Where $\Delta\varphi$ = measured potential difference
$\rho$ = resistivity of the soil
j = current entering or leaving the pipe surface
Therefore $j = \frac{\Delta\varphi}{0.734\rho}$

**4.3.2 Rate of pipe thickness loss**

$$W = kIt \qquad (5)$$

Where;
W = weight of metal reacting in gram
$k$= electrochemical equivalent (constant)

 

I= current entering or leaving the pipe surface in ampere
t = time in seconds
*k*, for carbon steel = $4.29x10^{-4}$

## 5. Conclusion

This study outlined appropriate methods to measure pipe to soil potential difference, soil resistivity, and pipe thickness loss. It further articulated the likely sources of stray currents within the Niger Delta region, the telluric effect of the sun to errors in pipe to soil potential readings, and suitable control measures against stray currents. The values obtained for the first pipeline were within the range of negative 710mV-810mV and were enough to cause corrosion on the pipeline. The second pipeline had this range of values except that they were random The second pipeline had a higher corrosion rate of 1.72x10-6g compared to that of the first pipeline of 1.42x10-6g due to the telluric effect of the sun.

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