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Proactive Pipeline Corrosion Monitoring Using a Telemetry System in the Ukanafun-Calabar Pipeline Route, Nigeria

Joseph J. Akpan[1] and John F. Wansah[2]

1. Chemical Engineering, Federal University Wukari, Taraba State, Nigeria
2. Pure and Applied Physics, Federal University Wukari, Taraba State, Nigeria

Abstract:
Oil and gas pipeline systems in the crude oil refineries play a critical part in exploration, exportation and delivering of petroleum products and the energy resources required to power communities around the globe. The necessity to protects and secures these structures and prolong their valuable service life remain extreme economic importance since their disappointment will impact negatively on life, environment, and properties. The extra or additive cost for pipeline corrosion management represent a very small percentage of the original system constructional costs. The price of employing a corrosion control scheme has established to be of countless benefits in curtailing seepages and at the same time prolonging the service life of the pipelines. In this academic work, oil and gas pipelines was giving a pro-active attention by monitoring in situ and remotely for corrosion effects using the telemetry system with measured and calculated result.

Keywords: Cathodic protection, Corrosion control, Corrosion monitory, Pipeline corrosion, Telemetry

INTRODUCTION

The conveyance of oil and gas via pipelines at present, remains the most significant means of transporting these products across different terminals in the Niger Delta region of Nigeria, both for export and for local consumption. This conveying medium "the pipelines" are suppressed and buried in the corrosively hostile seaside soils. Though its can be reasonable to think that, with the intricate coating techniques that is place today, the menace of soil corrosion would have extinct. However, whether due to fault of manufacturer or that of Engineering design, materials deterioration after burying of these pipes underground is still a common challenge. According to the academic works of [1,2], they considered that the most economical means of prolonging the service life of oil pipelines is by combining a suitable coating technique with an application of cathodic current ran from an external anode. Cathodic protection (CP), [3] is a corrosion protection technique that is employed to abridged corrosion reduction of a metal surface by making that surface to function as a cathode of an electrochemical cell. This method, cathodic protection CP and corrosion control can be tenuously or remotely monitored using Pipeline Telemetry System (PTS). [4] recognized this system as a system that transmit data captured by instrumentation and measuring devices to a remote or an inconvenient station where it is processed and utilized. The used of the cathodic protective technique has been reported date back to 1824 by Sir Humphrey Davy [5], he had a successful cathodal protection against corrosion attached coupled to zinc, Edmund Davy also successfully protected the ironwork of buoys by attaching zinc block in 1829, also, cathodic protection was explored by the Canadian seagoing ships in 1950, [5]. The design or construction of a typical CP structure depends upon several variables, such as quality of the pipeline coatings, the soil resistivity, the length of the pipeline to be protected, availability of power, these are variables that always call for independent investigation and analysis, [6]. The work of [7], suggested that CP can be achieved in two ways galvanically and electrolytically. In galvanic or sacrificial cathodic protection, the disintegrating objects made to serve as the cathode in the galvanic cell, while the anode, which is a metal of Mg, Zn protects a valued steel structure. The anode in this event is referred to as the sacrificial anode since it is the one been consumed through the course of protecting the steel structure. In considering Ukanafun-Calabar pipeline route, our area of study, record of the pipelines here are in remote settings with no access to national electricity supply line, even at the event of availability of the grid electricity, it is not suitable due to the instability and non-constant in supply. In this work, we decided to make do with a cheaper, steady, and reliable source of power, the solar power, to generate a direct current (DC) for the cathodic protection of the pipelines. This is because this energy can be obtained both in the rural and urban centers at a low cost and the arrangement will require little or no attention in putting it to operation aside the fears of local vandals. Also, the scheme has an added advantage of generating a steady DC power supply all year round.

ECONOMIC IMPACT OF CORROSION IN THE OIL AND GAS INDUSTRY

It has been observed by industry experts that, the total yearly cost of corrosion in the oil and gas industry can be express in monetary value to the tune of 1400 billion US Dollars. Giving the breakdown, shows $590 million dollars been expended in external pipeline and capacity costs, yearly expenses of $464 million in downhole pipes and another $322 million principal costs on other corrosion related cases [8] It is generally recognized in the industry that effective investment into corrosion monitoring and control management will not only contributed to the cost reduction but will at the same time ensure compliance with safety, health, and environmental policies [9]

In Nigeria, millions of naira are expended yearly in upkeeping and replacement of corroded oil and gas pipelines owing to the reaction of the pipes with their environment. if this situation continues unchecked, a hunk of the country resources will continue to go into corrosion control annually for the purpose of pipeline preservation, replacement, and other ecological related issues. Therefore, there is an urgent need to arrest this scenario via proper design, adequate cathodic protection, and the application of contemporary remote corrosion monitoring methods. According to [10], corrosion monitoring is helpful in measuring the pipelines degradation (integrity) and keeping the system corrosion rate at an acceptable limit through the application of suitable corrosion control techniques. The gravimetry method according to [11], is one of the physical allowable techniques within the industry used in determining quantitatively, the efficacy of cathodic protection using the formula:

$$S_{CP} = \frac{M_O - M_1}{M_O} * 100\% \text{ ....1.1}$$

Where M_0 is noted corrosion loss of an unprotected steel
M_1 is corrosion loss of a cathodic protected steel.

The corrosion rate [12] calculated using the formula:

$$\text{Corrosion rate (mpy)} = \frac{534W}{DAT} \text{ ......1.2}$$

Where mpy is mils penetration per year (umyr^{-1}), W is weight loss (g), D is density (g/cm^3), A is the area (cm^2) and T is time (hours).

GENERAL CORROSION

Corrosion is the unprompted destruction and a degenerative condition of pipelines because of either chemical, electrochemical, or biochemical interaction within the internal or external environment [13], it is a destructive attack on metallic material through chemical or electrochemical reactions within a period of environmental interfacing [14]. Giving a metal electrode within a liquid that comprises ions of the very metal, a potential difference between the metal and the liquid will be form [15].

$$\mathrm{M^{n+} + ne \Leftrightarrow M} \text{ ....2.1}$$

M is for metal, M^{n+} is the oxidized metal, ne is the number of electrons.

The potential difference (Pd) can be measured by making comparison with the reference electrode when the Pd within the two points is known. The definitive reference is the standard hydrogen electrode, the potential of which is defined as zero.

$$\mathrm{H_2 \Leftrightarrow 2H^+ + 2e} \text{ ....2.2}$$

Taking H_2 as the Hydrogen, H^+ is the hydrogen ion, and e is the electron.
This applied to the general form:

$$a_{Ox} + ne \Leftrightarrow b_{Red} \text{ ....2.3}$$

a and b are taking to be the redox coefficient, Ox is the oxidation, ne is the electrons, while Red is the reduction.

PROTECTION OF OIL AND GAS PIPELINES

It's been recognized that, there are about 528000km of natural gas transmission and gathering pipelines, 119000km of crude oil transmission and gathering pipelines around the United State of America, and current investigation of major pipelines firms shows that the main reasons behind loss of underground pipelines was because of; (i) coating weakening, about 30% and (ii) insufficient cathodic protection at 20% [16]. The remaining of which is the general system maintenance that is associated with monitoring and repairs of the pipelines.

PREVENTION AND CONTROL TECHNIQUE OF CORROSION

Carbon steel remain the most used steel in pipeline design and construction in the oil and industry. This steel and many others are protected in divers' ways and for a diversity of reasons such as wear resistance, corrosion resistance, lubrication for aesthetic appearance [17]. Both organic and metallic coatings are applied on pipeline to offer protection against corrosion attack on metallic surfaces [18].

Cathodic Protection

Cathodic protection (CP) is considered as the most real and effective method of preventing oxidation of an underground metal structures. This is obtained by imposing between the structures and the ground a small electrical voltage that opposes the flow of electrons and is stronger than the voltage present in the oxidation process [19]. The cathodic protection is divided into two main methods: the sacrificial anode (galvanic) and the impressed current.

Sacrificial Anode Method

In sacrificial anode or galvanic cathodic protection, the technique employs the natural potential difference (pd) that occurs amid the structure and a second metal within the environment to provide the supplying voltage. The corroding material made the cathode of a galvanic cell, the anode of which is a more reactive metal like magnesium, aluminum, or most cases zinc, which will by being sacrificed, gives protection to the valued structure [20]. No power source is needed, and this is demonstrated in Fig.1. However, the dissolution of this second material (Mn, Al, Zn), the sacrificial anode offers the basis of electrons for the cathodic polarization of the structure.

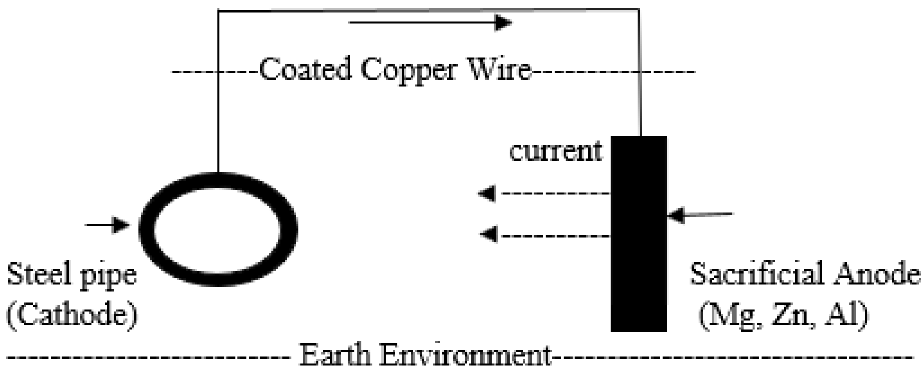

Fig. 1; Underground Pipeline Protection (Galvanic Cathodic)

Impressed Cathodic Protection

The technique of impressed current cathodic protection pedals the corrosion of a metal surface by making it the cathode of an electrochemical cell. This method of fortification links the metal to be protected to a more straightforwardly corroded material "sacrificial metal" to perform as the anode. Impressed current cathodic protection (ICCP) systems are classically mounted to prevent corrosion of metal underground piping systems and associated metal storage tanks. In an impressed current system, current is discharged from anodes sited in the identical electrolyte (soil) in which the piping or tank to be protected are buried. The impressed cathodic protection system needs the installation of an outside power supply which offers a direct current (DC) output as current supply from the alternative source (AC) is erratic and considered not to favor the Cathodic protection [1]. The impressed protection polarization designated by the generator method is presented in Fig.2.

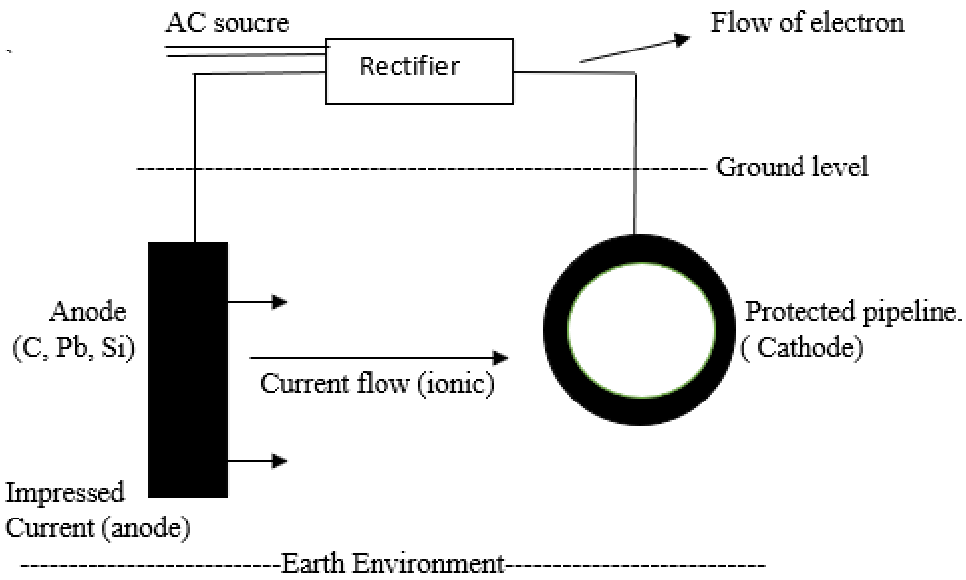

Fig.2, Cathodic Protection with impressed method.

The Cathodic Protection Requirements

There are two known types of electrical power source active in Nigeria and same is obtainable at the site of this work (**ukanafun-calabar pipeline route**) Akwa-Ibom, the renewable energy, and the non-renewable energy sources. The non-renewable will easily run out of used as its supply is limited but the renewable energy source is unlimited, and its supply is ever guarantee. According to the academic contribution of [21], the sun remains one of the renewable energy sources that can be harnessed using Photovoltaic modules.

The Photovoltaic Modules Systems

The photovoltaic (PV) cell, referred to as a solar cell is a solid-state electrical component that produce electricity when exposed to photons, or particles of light and this alteration effect is called the photovoltaic effect. Photovoltaic arrangements provide a suitable and cost-effective solution for the delivery of steady and fairly small amounts of power required for a wide range of application [22]. Photovoltaic systems need no fuel, requires little maintenance input and it is environmentally friendly. This energy system present itself as the only suitable energy option for the provision of electricity at the remote site. According to the reviewed work of [23], solar remote power systems are dependable alternative anywhere the grid power is not accessible.

Stand- Alone PV System

A stand-alone photovoltaic system is an electrical arrangement which consisting of an array of one or more PV modules, conductors as well as electrical mechanisms with one or more load. Stand-alone PV system is a self-sufficient system that is connected to the grid and can have a back-up arrangement. This structure is connected directly to the applicable device and the power is supply during sunshine hours, with a battery storage arrangement to store up power for the night [24,25]. Fig.3. indicate the stand-alone PV arrangement under remote cathodic protection of pipelines.

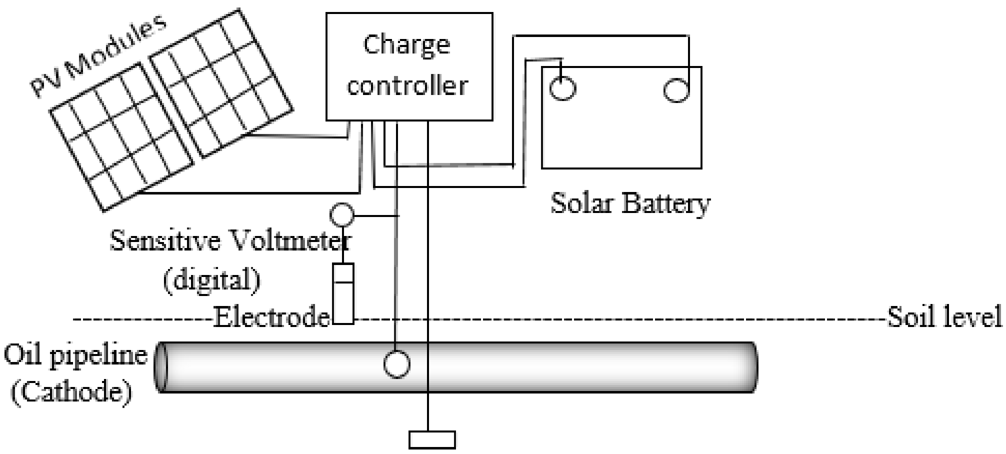

Fig.3. Cathodic Protection of oil Pipeline using PV modules.

Pro-active Monitoring Practices and Cathodic Protection of Oil Pipelines

The Cathodic Protection (CP) techniques are considered the most efficient and effective method of pipeline corrosion monitoring. Applying the modern electronic and communication gadget for isolated monitoring, lessens the operating cost. Located away from the platform, data can be generated and analyzed to aid in the maintenance of the entire system, eliminating waste of resources on manpower and cost of movement associated with the traditional approaches. A digital multimeter is used in monitoring the structure-to-soil potential at the test post. This is instinctive to record figures systematically, to create reports, sense, and report failures at the locations [26]. This remote monitoring or pro-active technique allows industry experts and engineers to monitor cathodic protection arrangements in an isolated location. This method of corrosion monitoring and control is dependable, with the deployment of few manpower, data can be collected from hundred and thousands of locations within a day or days

METHODOLOGY

According to [6], Cathodic Protection methods is design to offer a desired amount of protection at the least total yearly cost over the predictable life of the protected oil pipeline. The material used for the work were provided by the oil firm and the work was carried out under the supervision of Pipeline and Product Marketing Company (PPMC), a subsidiary of the Nigerian National Petroleum Cooperation (NNPC). The design networks were made to the telemetry monitoring circuit, data logger and a laptop computer connected for a real-time, supervising many kilometers away from the location of the oil pipeline Fig.4. The test post was set at every one (1) kilometer apart, where the oil pipeline is cathodic protected from corrosion attack and reading was taken. Electrical measurement, as well as inspection was carried out to certify that the essential protective potential had been established in accordance with the applicable criteria, also that each point of the cathodic protective system function correctly.

The Anode Bed Design Installation's Calculation

The value of a single anode resistance to earth can be calculated using Dwight's equation and the number of anodes required can be established [27]:

$$R_a = \frac{0.1588\rho}{L}\left[ln\frac{8L}{D} - 1\right] \qquad \text{.......................1.}$$

R_a represents the anode resistance in ohms (Ω), ρ is the medium resistivity measured in $(\Omega - m)$, L is the length of the anode in meter (m) and D is the anode diameter (m). The sum resistance of the anode as well as the ground bed resistance, having in mind the mutual interference is obtained using the Dwight's equation [27].

$$R_{gb} = \frac{R}{N}\left[\frac{\rho}{\pi N S}\right] ln 0.66xN \text{........................2.}$$

The ground bed resistance R_{gb} in ohms (Ω), the number of anodes is represented by N, R is a single anode resistance in (Ω) while S represent the anode spacing in meter (m).

To establish the minimum required current for cathodic protection, this is given by.

Oil pipeline superficial area $A = \pi(D + 2tw)L$................3.

For minimum current density required is (Ma/m²). While the modified temperature is (C_1) (A/m²)
The cathodic protection minimum required current is: C_1 x A.

The Cathodic Protection Installation

According to the academic work of [6], the following major points were noted during the process of the installation, Fig.4.,

a) The coke breeze was carefully tamped, as any loose in the backfill can result in high resistance and shortened of the anode lives.
b) The buried connections were secured with extreme defenses from the entrances of any moisture, as a discharge of current to the earth surface from the cable will cause damage to the se-up within days.
c) Cable connection to the anode was protected as any allowable crack will license the entering of moisture that will in-turn give room to system failure.
d) The anodes were suppressed at a satisfactory depth, guarded, against unintended damage

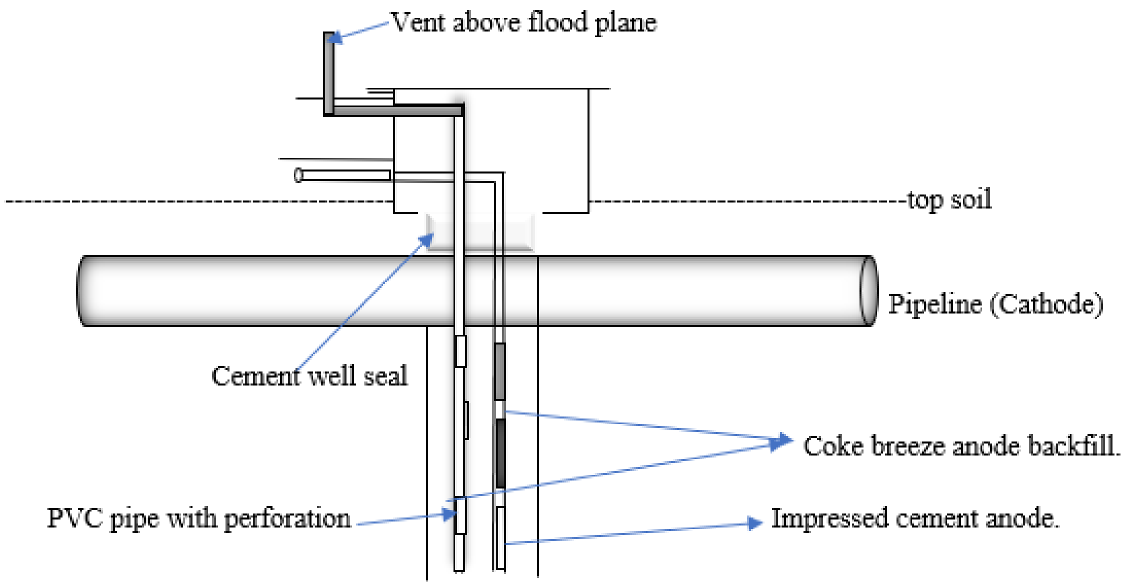

Fig.4: Anode Ground Bed

The installation (pipeline) will be cathodic ally sheltered or protected against corrosion attack. The electrical measurement and review will be carried out to ensure that the required guard potential is established according to the relevant criteria, and that each part of the Cathodic protection system operating correctly, by this remote corrosion is properly checked and the pipeline performance maintained.

The Remote System Network

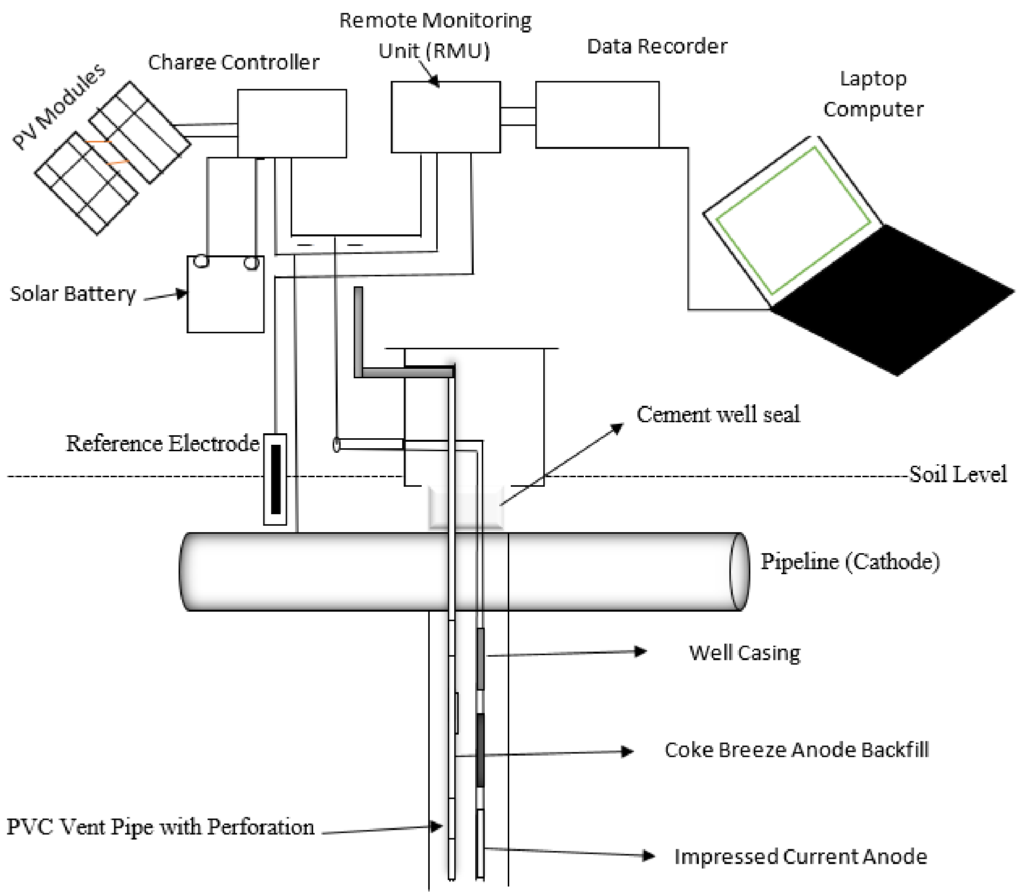

Fig.5. Cathodic Protection and Corrosion Remote Monitoring Component

TEST AND RESULT

At the oil pipeline site of Ukanafun-Calabar NNPC pipeline route, Asang, Akwa-Ibom state, some tests and result of the remote monitoring of pipelines was conducted using telemetry, below is the breakdown of the reading on table 1. and its graphical interpretation on Fig.6. respectively.

Table 1.; Post and Telemetry Cable Pipe-Soil Potentials

Test Post Numbering	Post Pipe-Soil Potential (-mV)	Telemetry Cable Pipe-Soil Potential (-mV)	Difference (mV)
1.	955	955	000
2.	855	857	002
3.	854	842	012
4.	817	836	019
5.	753	758	005
6.	895	893	002
7.	914	945	031

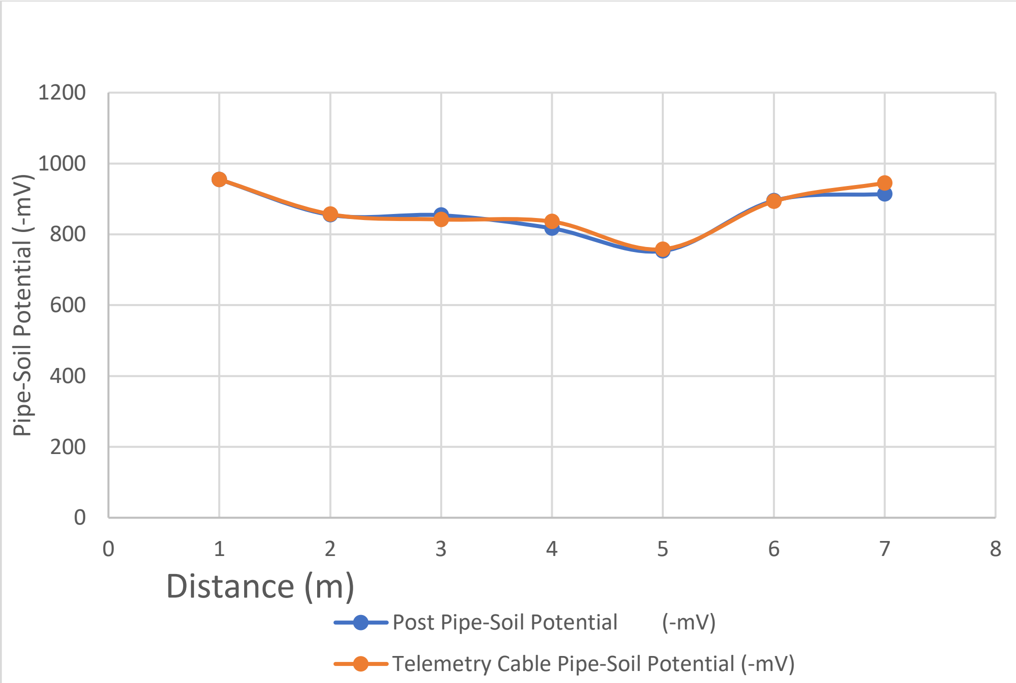

Fig.6.; Post and Telemetry Cable Pipe-Soil Potentials

The above data on Table 1. and Fig.6 display a very close reading with a slight difference among post pipe-soil potentials and telemetry pipe-soil potentials.

From -850 mV, the protection is active and when it goes below -2000mV, it becomes injurious to the pipeline coating system.

CONCLUSION

In the installation, two main methods were setup to run simultaneously, the impressed current and the sacrificial anode. While the sacrificial anode utilizes the corrosive potential created by different metals, the impressed current designates the decreased of the output current because of the anode dissolving into the engrossed saltwater. A steady of power from the photovoltaic cell (solar panel) will maintain a constant check on the corrosion rate of the pipeline but a drop in power supply or an outage will cause a reverse in the protection process.

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