

CATHODIC PROTECTION STATE OF ART REVIEW AND UPGRADING TECHNIQUES

(A Report on Project I)

*Submitted as a part of course work in
M. Tech (Pipeline Engineering)*

By
Venkata Rama Krishna.G
B.Tech (Electrical Engg.)

Under the Guidance of

Mr. P.Suresh Kumar
Assistant Professor
Rajahmundry, Andhra Pradesh



COLLEGE OF ENGINEERING STUDIES
UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
Rajahmundry Regional Centre
Rajahmundry-533 294
Andhra Pradesh

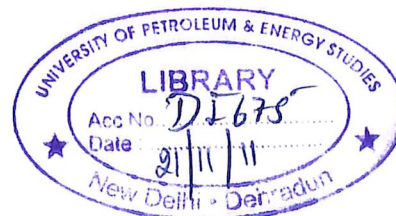
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Certificate

This is to certify that the project work entitled “*Cathodic Protection State Of Art Review And Upgrading Techniques*” being submitted by **Mr. Venkata Rama Krishna.G**, in partial fulfillment of the requirement for the award of the degree of Master of Technology in Pipeline Engineering in University of Petroleum and Energy Studies-Rajahmundry, is bonafide project work carried out by him under my guidance.

Mr. Venkata Rama Krishna.G fulfills all the requirements of the regulations laid down for the award of the degree of Master of Technology.

The content of this report has not been submitted to any university or institution by me or him for the award of any degree or diploma.

Rajahmundry

Date:



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Mr. P.Suresh Kumar
Assistant Professor

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G.V.Rama Krishna
(G.V.Rama Krishna)

Abstract

Study on Cathodic Protection State of Art Review & Upgrading Techniques along VVSPL (Vizag-Vijayawda-Secundrabad Pipeline). This project about why the upgrading is needed & which type of upgrading can be done. The study should also account for the external interference the section has to face during its lifetime.

The upgrading is proposed due to the pipeline is not protected properly from corrosion. The Pipe to Soil Survey potential (PSP) of few chainages are found to be abnormal.

Determination of Current drains along the section of pipeline includes:

- Soil condition
- Coating condition (current density)
- Condition of the pipeline section when C.P ON and OFF
- Existence of stray currents.

The above variables have to be found out experimentally in order to find the exact requirement for upgrading. The study shows the general procedures and considerations. The upgrading requires a huge amount of analysis technically, economically as well as geographically. That requires about 572KM (between Vizag to Secundrabad) of field survey to find current drain points. The upgrading is only feasible way that the C.P station satisfies the requirement and without affecting the structure.

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Chapter -I

INTRODUCTION

WHAT IS CORROSION?

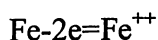
Although there is no simple answer to the question, "what is corrosion?" There are people believe that corrosion is oxidation. Others feel it is a chemical attack. Somebody says that is an electrical phenomenon. None of the above answers tell us much, although each one is partially true. One general definition of corrosion is the degradation of a material through environmental interaction.

1.1 ELECTROCHEMICAL THEORY OF CORROSION:

There are electro chemical changes taking place when a metal corrodes. Metal is generally hard, firm, dense, opaque, insoluble in water and it conducts electricity. But metal can also exist as ions. The metal ions are soluble in water, they are positively charged whereas the metal is neutral, and they help to carry electric current through a solution.

The electro chemistry of corrosion deals with change of metals to ions, and ions to metals or gases. When a metal changes to ions, that is corrosion. The smallest particle of matter is called electron, it has no weight but has negative charge of electricity. It is represented by letter 'e'. It is found in all atoms and it is part of all atoms. It cannot exist alone. When an atom loses one or more electrons it becomes an ion.

Fe is iron atom



Fe^{++} is iron ion

The iron atom has lost two electrons. Iron undergoes tremendous changes in its properties when above reaction takes place. The change represented by above reaction cannot take place alone. This brings us the subject of electrolyte cells.

1.2 ELECTROLYTE CELLS:

When ever two metals are immersed in water, a voltage is set up between two metals, unless the metals are absolutely alike or the water is absolutely pure. If the water has some salt or acid dissolved in it, the voltage is greater .If the two metals are different, that too makes for greater voltage than a cast iron steel combination. This combination of two metals called electrodes, dipped in a conducting solution called an Electrolyte. If cell produces voltage it is called voltaic or galvanic cell. If two electrodes are connected by a wire, current flow from one electrode called anode through electrolyte and out of solution through other electrode called cathode.

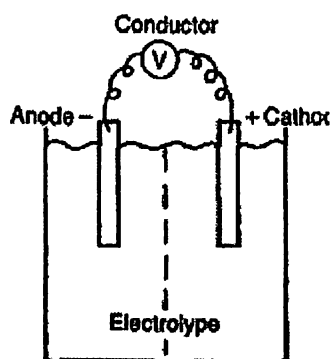


Figure 1.1 Dissimilar electrode cell

There are few fundamentals regarding electrolyte cell that we need to remember. When a current flows through a cell, there is always some chemical change taking place at contact between anode and electrolyte and the contact between cathode and electrolyte. These chemical changes can be far reaching importance in corrosion control.

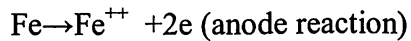
In many cases the anode wastes away, it forms ions means corrodes. The cathode on other hand is usually unaffected by chemical change taking place at its surface. The following principles of an electrolyte cell:

- A. Anode corrodes
- B. Cathode does not corrodes
- C. There must be an electrolyte for currents.
- D. There must be connection between the two electrodes.

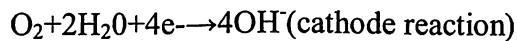
In all cells electrode can be properly labeled plus (+) and minus (-). It should be noted current always flows from anode to cathode in electrolyte in all cells under all conditions.

1.3 BASIC CORROSION REACTIONS:

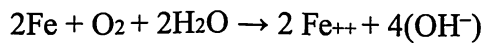
When iron or steel corrodes, there is always an anode and cathode, an electrolyte and a return circuit. The corroding action at anode will be



At the cathode, reduction of oxygen would occur:



The combined anodic and cathodic reactions will be



The oxidation reaction is commonly called the anodic reaction and the reduction reaction is called the cathodic reaction. The oxidation reaction causes the actual metal loss but the reduction reaction must be present to consume the electrons liberated by the oxidation reaction, maintaining charge neutrality.

1.4 WHAT IS ELECTROLYTE IN CORROSION?

An acid or salt solution makes a good electrolyte and corrosion in such solutions is rapid. But ordinary tap water or river water is sufficiently conductive to permit corrosion reactions to take place. Even rain water as it falls through atmosphere, dissolve sufficient carbon dioxide to make it conductive and in industrial areas or near the sea shore; it may dissolve a variety of compounds to make it very conductive. It is not even necessary for visible water to be present for corrosion to take place, all objects have a thin water film on their surfaces. This film is so thin we do not detect it by our usual senses, but even it can serve as an electrolyte to permit corrosion. A piece of iron located under roof where it never gets wet, will just not as rapidly as when it is wet but over a period of few weeks, rust can be detected.

1.5 CORROSION IN PIPELINE:

Corrosion in pipelines is internal & external corrosion. Here my project deals with external corrosion.

Corrosion in pipeline is basically electro chemical in nature and presence of oxygen is a must for corrosion to take place. Corrosion in pipeline in which a current leaves a structure at the anode site, passes through an electrolyte (soil), and reenters the structure at the cathode site as figure shows For example, one small section of a pipeline acts a anode because it is in soil with low resistivity compare to rest of pipeline. Current flows from anode site, pass through the soil and reenter the current at cathode site. Current flows between anodes to cathode due to potential difference .Anode potential is more negative than the cathode potential , and this difference is the driving force for corrosion current. Anode, Cathode, electrolyte and metal connection between anode & cathode.

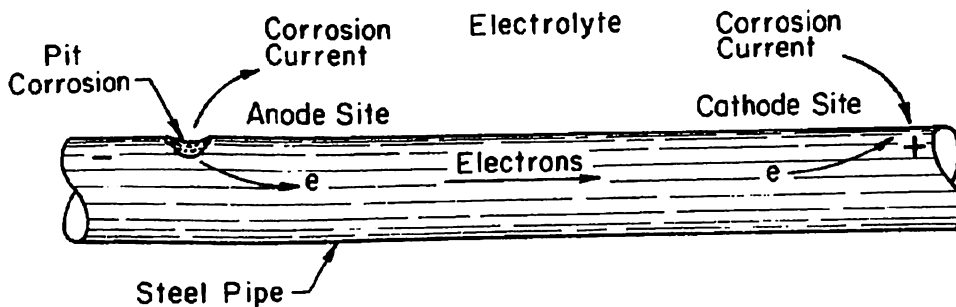


Figure 1.2 Electrolyte cell formed on the pipeline

1.6 HOW DO WE DETECT CORROSION IN PIPELINE?

The electrochemical nature of the corrosion process provides opportunities to detect and mitigate corrosion of underground structures. We can monitor the voltages and the currents associated with the corrosion process.

When a piece of metal is placed in an electrolyte (soil), a voltage will develop across the electrolyte- metal interface because of the electrochemical nature of the corrosion process. This voltage is cannot be measured directly but, using a voltmeter, we can measure a voltage between two different metals that are placed in the soil. The voltage difference between a metal and a reference electrode is named as half-cell electrode. This voltage is

referred to as a corrosion potential, an open circuit potential, or a native potential for that metal in the environment in which the measurement is being obtained. For soil environments, the most common reference electrode used is the copper–copper sulfate reference electrode (CSE).

Potential measurements can be used to estimate the relative resistance of different metals to corrosion in a given environment. Noble metals, such as gold and platinum, have more positive potentials and are more resistant to corrosion than are the more common engineering metals such as steel and aluminum. A galvanic series is a list of metals and alloys arranged according to their relative corrosion potentials in a given environment. Table 1.1 shows a galvanic series for metals and other materials in neutral soils and water, indicating that carbon has the most positive potential of the materials listed and magnesium has the most negative potential.

Table 1.1 Practical Galvanic Series for Materials in Neutral Soils and Water

Material	Potential Volts (CSE)
Carbon, graphite ,coke	+0.3
Platinum	0 to -0.1
Mill Scale on Steel	-0.2
High Silicon Cast Iron	-0.2
Copper, Brass, Bronze	-0.2
Mild Steel in Concrete	-0.2
Lead	-0.5
Cast Iron (Not Graphitized)	-0.5
Mild Steel (Rusted)	-0.2 to -0.5
Mild Steel	-0.5 to -0.8
Commercially Pure Aluminum	-0.8
Aluminum Alloy	-1.05
Zinc	-1.1
Magnesium Alloy	-1.6
Commercially Pure Magnesium	-1.75

Potential measurements are commonly used on underground pipelines to detect the presence of these types of differential corrosion cells. An electrical connection is made to the pipe, and the potential of the pipe is measured with respect to a reference electrode placed over the pipe. This process is shown schematically in Figure 1.2. Normally, the reference

electrode is connected to the negative lead of a digital voltmeter to obtain a negative reading. As shown in Table 1.1, most potential in soils are negative. With this type of measurement, the most negative regions of the structure are the anodes and are undergoing accelerated corrosion due to the differential corrosion cells. The anodic and cathodic sites on the pipeline can be located by performing a series of cell-to-cell potential measurements taken along the pipeline.

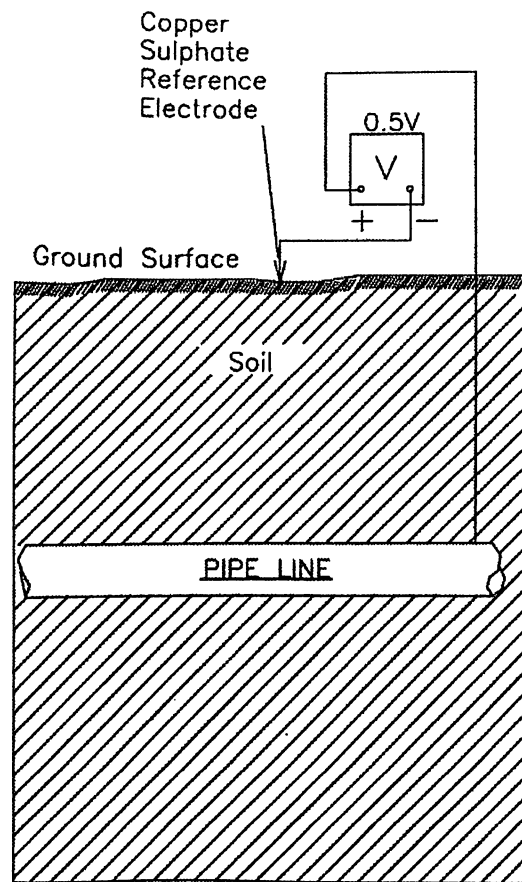


Figure 1.3 Showing pipe to soil potential measurement

Chapter-II

MITIGATION OF CORROSION

There are several ways of preventing corrosion although some may not be practical or economical for particular item being considered.

Different methods are:

- Alternative materials
- Changing the environment
- Design
- Coating
- Use of Inhibitors
- Cathodic protection

2.1 ALTERNATIVE MATERIALS:

Some metals principally at noble end of electro chemical series of metals are very stable when placed in moist soils or waters and will not corrode. Gold, Silver and Platinum are obvious examples together with some grades of stainless steel. Economic considerations would normally prohibit their use.

The corrosion resistance of metals is greatly improved by

- Change of composition: The resistance of metallic material can be improved by changing its composition by either refining or alloying
- Change of structure: Changing the structure of a metal heat treatment or cold working can improve its corrosion resistance.
- Elimination of tensile stresses: Elimination of residual tensile stress by stress relief annealing treatment can often improve the resistance of a material to several types of corrosion failures, such as stress corrosion cracking, hydrogen embrittlement etc.

2.2 CHANGING THE ENVIRONMENT:

At normal potentials steel or iron can be inhibited from corroding if the PH of the electrolyte is made alkaline within certain levels. This technique is basis of certain water treatments where chemicals are added to water or pipelines carrying cooling water to inhibit the internal corrosion. In many cases changing or modifying the corrosion environment can effectively control corrosion. Following methods have been used for this purpose.

Removal of Corrosive constituents

Removal of corrosive constituent of the environment can effectively prevent corrosion. Few examples are:

- a. Removal of moisture from air by dehumidification, e.g. using silica gel in small closed spaces.
- b. Removal of oxygen from water by (i) saturation with inert gas e.g., nitrogen (ii) addition of oxygen scavengers e.g. hydrazine (N_2H_4) or sodium sulphite.

2.3 DESIGN:

The prevention of corrosion must begin at the design stage, and full advantage should be taken of the range of protective coatings and corrosion resistant materials available. The design engineer can take precautions during the basic design to minimize the possibility of corrosion for instance by avoiding the coupling together of dissimilar metals.

2.4 COATING:

This technique aims to separate the metal surface from electrolyte there by any electrical circuit that might arise and preventing corrosion current from flowing. This is generally the only technique available some being more efficient than others. Generally used pipeline coatings are

- Coal tar enamel
- Fusion bond epoxy
- Three layer polyethylene
- Heat shrinkable coating

Although coatings by themselves may not be the one perfect answer to corrosion control, they are extremely effective when properly used. None of the above said coating provide perfect barrier between the metal surface and electrolyte. Most operators plan coatings and cathodic protection (CP) for all their pipelines as a matter of course. Coating is very useful in reducing the amount of cathodic protection current required. A typical well-coated pipeline this should be better than 99% and, along with the CP, should give total protection.

2.5 USE OF INHIBITORS:

Inhibitors are substance which when added in small quantity to a corrosive environment, lower the corrosion rate. They reduce the corrosion by either acting as a barrier, by forming an adsorbed layer or retarding the cathodic and / or anodic process. A cathodic

inhibitor increases the cathodic polarisation and hence moves the corrosion potential in the anodic directions, whereas an anodic inhibitor increases anodic polarisation and displaces the corrosion potential in the negative direction. A substance which increases both the cathodic and the anodic polarizations are called mixed inhibitors, the potential change in these cases is small and its direction is determined by the relative degree of the cathodic and anodic effects.

The protection inhibitors can be classified under the following groups:-

- Chemical passivators: These substances usually have a sufficiently high equilibrium potential and sufficiently low over potential and are called chemical passivators, oxidizers or oxidizing inhibitors. Typical examples are chromate, nitrite, and ferric salts.
- Adsorption inhibitors: Adsorption inhibitors are organic compounds, which get absorbed on the metal surface and provide a blanketing effect over the entire surface i.e. both anodic and cathodic cases. Generally they affect both anodic and cathodic reaction equally, but in many cases the effect may not be equal. The effectiveness of this blanketing depends upon several factors, e.g. size and distribution of the particles being adsorbed, nature of the electrical double layer etc.,
- Film forming inhibitors: The adsorption inhibitors which form a straight forward adsorbed film of the inhibiting species, many substances, called film forming inhibitors appears to stop corrosion by forming a blocking or a barrier film of a material other than the actual inhibiting species itself, e.g. zinc and calcium salts and benzoate
- Vapour phase inhibitors: Atmospheric corrosion of metals in closed spaces such as in parcels during storage and shipment can be prevented by the use of certain substances called vapour phase inhibitors (VPI). These are substances of low but significant vapour pressure, the vapour of which has corrosion inhibiting properties.

2.6 CATHODIC PROTECTION:

Cathodic protection is the process for reducing or elimination of corrosion on a metallic structure in contact with corrosion electrolyte by introducing electrolyte action greater in strength and opposite in direction to electrolytic activity-corrosion which would otherwise take place.

Chapter -III

CATHODIC PROTECTION

3.1 TYPES OF C.P:

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. This is achieved by applying a current to the structure to pipeline from some outside source or sacrificial anodes are made from metals that are more reactive than the metal to be protected. When enough current is applied, the whole structure will be at one potential, anode and cathode sites will not exist. Cathodic protection is commonly used on many types of structures, such as pipelines, underground storage tanks, locks, and ship hulls.

How cathodic protection works?

Corrosion is electrolytic in nature; it involves contact between a metal and an electrolyte. The corrosion is accompanied by a flow of current in the metal, in the electrolyte and from one to the other. Where the current leaves the metal, there is corrosion. Cathodic protection is simply a way of stopping the current by over powering in with a stronger current from an external source.

Methods of applying cathodic protection:

There are two methods of cathodic protection

1. Galvanic anode or Sacrificial Anode system
2. Impressed current system

3.1.1 Sacrificial Anode System:

Sacrificial anodes are made from metals that are more reactive than the metal to be protected. Their relative position in the electrochemical series of metals a potential difference exists between them which cause a small electric current to flow. As it gives up current the anode corrodes or scarifies itself.

The corrosion of an active metal such as magnesium or zinc generates the high potential electrons needed for protection. In this system, the anode material is consumed, or sacrificed in the process, and the anodes must be periodically replaced to maintain continuous protection. The anodes are designed with sufficient anode material that the anode

replacement interval is set at an economic desired number of years. For buried systems, common practice is to design the system for a 10- to 15-year anode life. For systems where anode replacement is difficult (expensive), longer (20- to 30-year) anode life is often used as design criteria. Figure 3-1 shows the working of a sacrificial anode system.

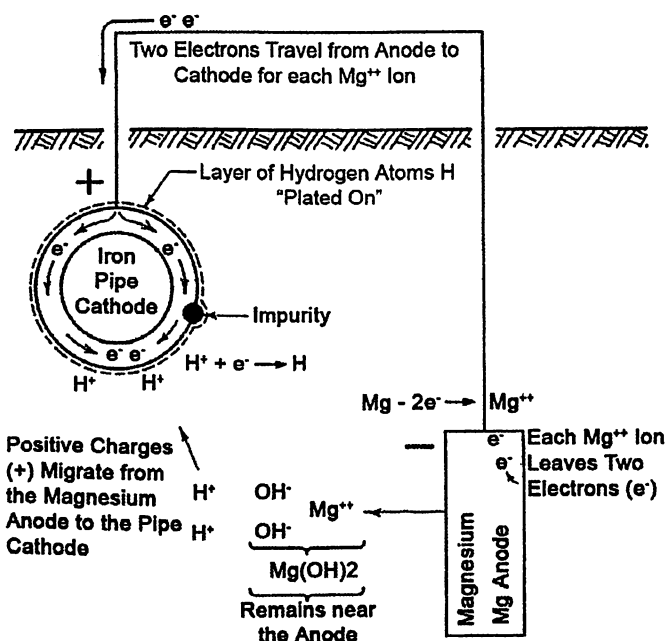


Figure-3.1: Sacrificial Anode System

The structure-to-electrolyte potentials required for protection with a sacrificial anode cathodic protection system. Due to the limited driving potential of sacrificial anodes, they must be located close to the structure being protected. Figure 3-2 shows a typical sacrificial anode system.

For the protection of pipelines, the anodes are not attached directly to the structure, but are placed in the soil, evenly distributed a short distance from the pipeline and connected to the pipeline by a metal wire, usually through a test station.

The application of galvanic anodes is limited by the small potential difference (normally less than 1 Volt dc) that can be obtained. Galvanic systems can only be economically used on small or well-coated structures in low-resistivity electrolytes. Since the amount of cathodic protection depends on the current density supplied to the protected structure, the electrolyte resistivity determines the amount of current that the limited voltage will supply and the amount of metal exposed to the electrolyte determines the amount of current required. Uncoated structures may require an exorbitant number of anodes for

adequate protection. In higher resistivity electrolytes, the small anode-structure voltage difference would yield (via Ohms law) an extremely small amount of anode current, hence requiring a large number of anodes. High purity magnesium anodes have the highest potential available, but in high resistivity soil, there would not be sufficient current to protect a structure unless it had an extremely good coating

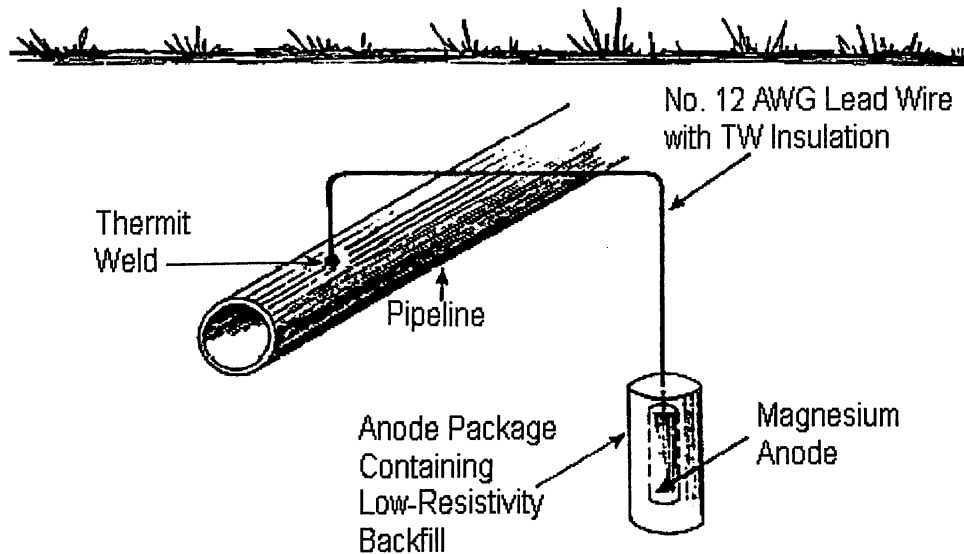


Figure 3-2: Typical Sacrificial Anode System Installation

The sacrificial anode system consists of the following components:

- Sacrificial anode
- Anode bed/backfill
- Interconnecting cable
- Test station
- Reference electrode

3.1.2 Impressed Current System

In an impressed current system, an external supply of direct electrical current is used to oppose the discharge of corrosion current from anodic areas. Electrical current is used to develop the potential difference between the anode and the pipeline being protected. This external current is supplied by a rectifier or other external dc power source instead of the potential difference of the anode with respect to the structure being protected. Table 3-1

provides the potential required for cathodic protection of various metals using an impressed current system.

Table 2.1: Potential Required for Cathodic Protection

Metal	Potential(cu/cuso ₄)
Steel	-850mV
Steel(sulphate reducing bacteria)	-950mV
Copper Alloys	-500 to -650mV
Lead	-600mV
Aluminum	-950 to -1200mV

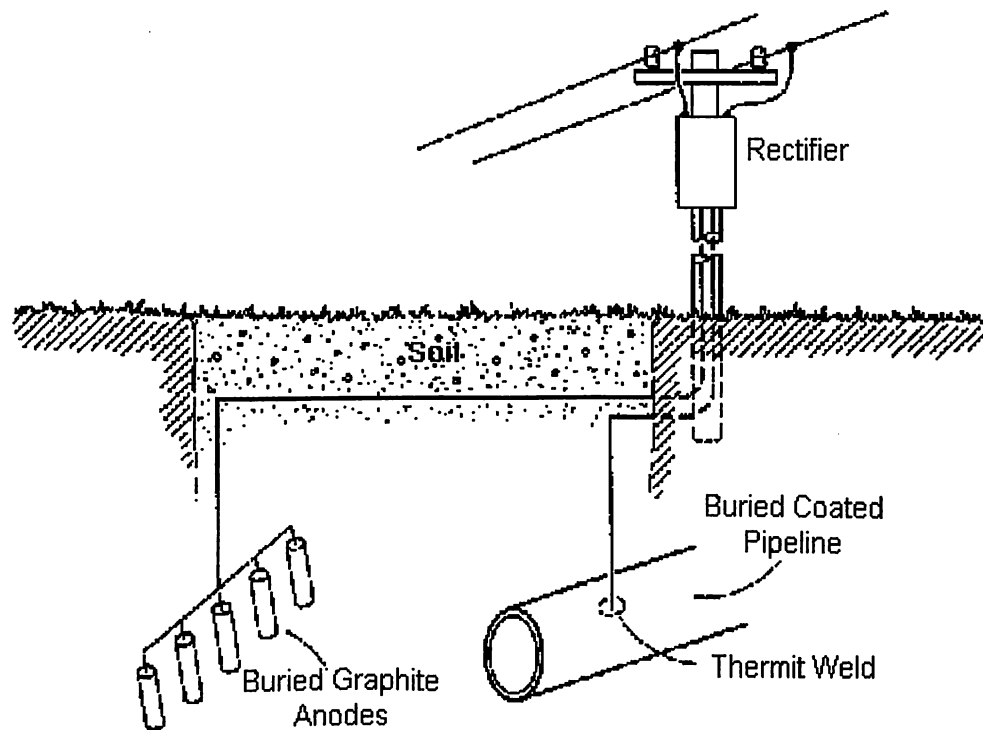


Figure 3-3: Impressed Current System

The external current is injected into the soil (or electrolyte) via engineered anodes. The anodes of an impressed current system provide the means for the protective current to enter the electrolyte and anode consumption is not the primary mechanism for generating the protective current. Materials such as graphite, high silicon cast iron, platinum, or mixed metal oxides are used as anodes because they have a very low loss of weight per ampere-year. Voltages of up to 100V and high current densities can be used. Therefore, large areas of structures can be protected by a single anode and due to the high driving voltages the anode

can be located remotely from the structure being protected. Figure 3-4 shows a typical impressed current system.

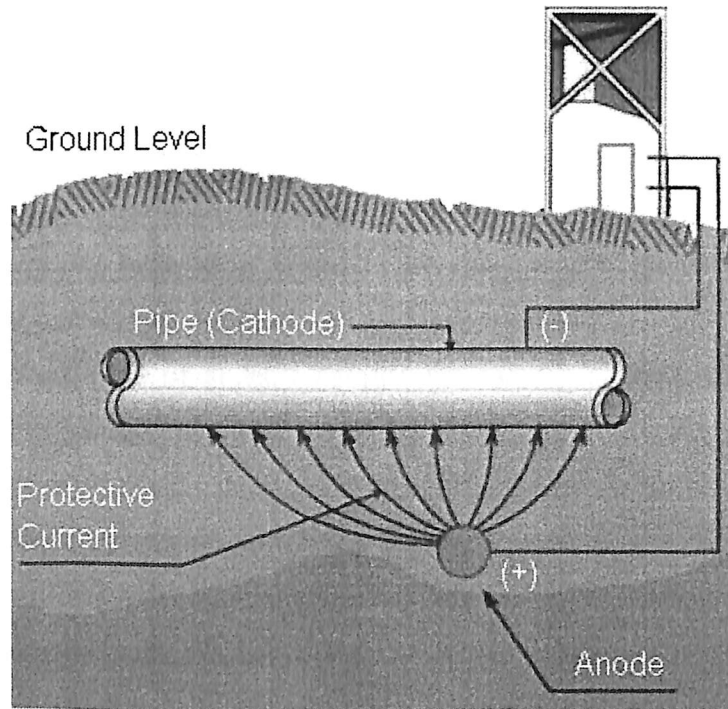


Figure 3-4: Typical Impressed Current System

A typical impressed system consists of the following components:

- Relatively inert anode
- Anode bed/backfill
- Transformer (where needed)
- Dc power source (rectifier, batteries, etc.)
- Inter connecting cables
- Control panel
- Circuit breaker
- Fuses
- Meters (current, voltage)
- Test station
- Reference electrode
- Anode junction box

3.2 CRITERIA FOR CATHODIC PROTECTION:

Three primary criteria for Cathodic Protection of underground steel or cast iron pipeline are listed in Section 6 of NACE Standard RP-01-69 (1996 Revision)

- -850 mV (CSE) with the CP applied,
- A polarized potential of -850 mV (CSE)
- 100 mV of polarization

3.2.1 850 mV with Cathodic Protection Applied Criterion

The full criterion states that adequate protection is achieved with:

A negative (cathodic) potential of at least 850mV with the CP applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement. Consideration is understood to mean application of sound engineering practice in determining the significance of voltage drops by methods such as:

- Measuring or calculating the voltage drop(s),
- Reviewing the historical performance of the CP system,
- Evaluating the physical and electrical characteristics of the pipe and its environment
- Determining whether or not there is physical evidence of corrosion.

3.2.2 Polarized Potential of -850 mV Criterion

This criterion states that adequate protection is achieved with “a negative polarized potential of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.” The polarized potential is defined as the “potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.” The polarized potential is measured directly after the interruption of all current sources and is often referred to as the off- or instant off-potential. The difference in potential between the native potential and the off or polarized potential is the amount of polarization that has occurred as a result of the application of the CP. As previously stated, the difference in potential between the on-potential and the off-potential is the error in the on-potential introduced as a result of voltage drops in the electrolyte (soil) and the metallic return path in the measuring circuit.

3.2.3 100 mV of Polarization Criterion

This criterion states that adequate protection is achieved with “a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.” Of the three criteria, this criterion has the sound fundamental basis. The corrosion rate decreases and the rate of the reduction reaction on the metal surface increases as the underground structure is polarized in the negative direction from the native potential. The difference between the corrosion rate (expressed as a current) and the rate of the reduction reaction is equal to the applied CP current.

3.3 SURVEY OF PIPELINE NOT UNDER CATHODIC PROTECTION

- Measurement of the electrical resistivity of the soil environment around the pipeline
- Determination of conditions suitable for anaerobic bacterial corrosion
- Determination of various chemical constituents in the soil environment (chlorides, sulfate, sulfides, bicarbonates)
- Potential surveys: measurements of potentials between pipeline and environment
- Line current survey: measurement of electrical current flowing on the pipeline
- Measurement of the effective electrical resistance of any coating on the pipeline being studied
- Bellhole examinations for evidence of corrosion activity
- Use of recording instruments for the study of unstable (stray current) conditions
- If cathodic protection (CP) is deemed necessary: evaluation of electric current requirements for CP.

3.4 SURVEY OF PIPELINE UNDER CATHODIC PROTECTION:

- Potential surveys: measurements of potentials between pipeline and environment
- Line current survey: measurement of electrical current flowing on the pipeline
- Measurement of the effective electrical resistance of any coating on the pipeline being Studied
- Bellhole examinations for evidence of corrosion activity
- Use of recording instruments for the study of unstable (stray current) conditions

3.4.1 Potential survey:

The potential difference between a pipeline and the soil is of considerable importance, either to know the corrosive conditions or in evaluating the extent of cathodic protection being applied. This quantity actually is measured by connecting an instrument between the pipe itself (direct metallic contact) and a special electrode placed in contact with the soil. This electrode is also called a half cell. The most common type of electrode in use is that which employs a metal-to-electrolyte junction consisting of copper in contact with a saturated solution of copper sulfate, this particular combination is made of easily available materials and is very stable

The silver/silver chloride electrode is used in seawater because it is not subject to contamination by salt incursion.

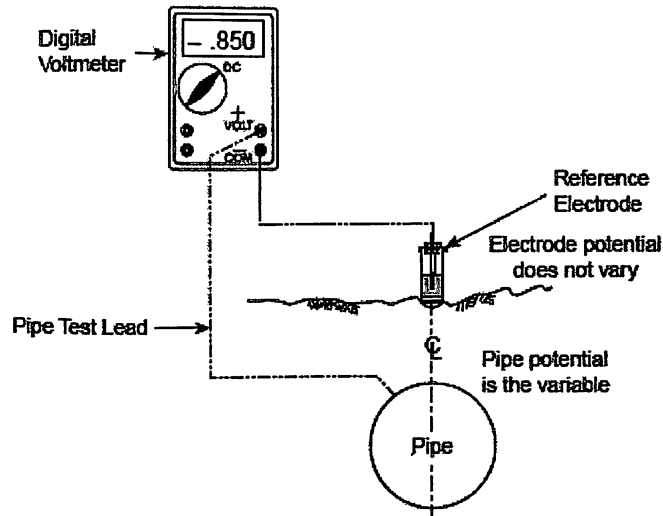


Figure-3.5: Pipe to earth potential measurement

3.4.2 Line current survey:

Measurement of pipeline current by the resistance drop method is useful in pipeline survey work. It is also useful in determining the distribution of current along a cathodically protected pipeline and for other applications such as stray current. The procedures outlined typically use permanent test points to contact the pipe. There are two methods for calculation of line current survey.

- a.) Permanent Two-Wire Test Points
- b.) Permanent Four-Wire Test Points

A.) Permanent Two-Wire Test Points

The two-wire test points spanning a known length of pipeline are available, currents may be measured by determining the potential drop across the span, selecting the Pipeline resistance from tables, and calculating the current using Ohm's law. The general arrangement is shown in Figure.

The procedure may be performed as follows:

1. Measure the circuit resistance of the test leads and pipe span by passing known battery current through the circuit and measuring the voltage drop across the test point terminals. Calculate resistance by Ohm's law: R (resistance) = V (volts) divided by I (amperes). If the resistance obtained is higher than reasonable for the size and length of test wires, defective leads may be suspected.
2. Measure the voltage drop across the test point terminals caused by the normal current flowing in the pipeline. Usually this will be millivolts. Instrument resistance must be known and correction made for the external circuit (measured in Step 1). Note the polarity of the meter connection to the test point terminals and indicate the direction of current flow (C to j) along the pipeline.
3. Using pipeline resistance tables, determine the resistance of the pipeline span
4. Calculate the pipeline current flow by Ohm's law. Current in mill amperes = corrected millivolt drop (from Step 2) divided by pipe span resistance in ohms.

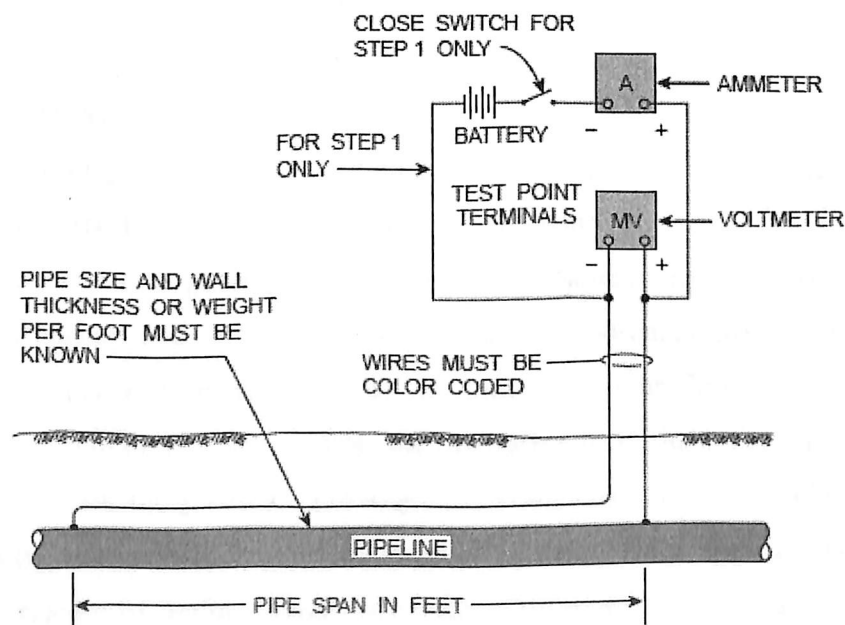


Figure-3.6: Current measurement with 2-wire test points

B.) Permanent Four-Wire Test Points

Pipelines having four-wire test points with two color-coded wires at each end of a current measuring span for accurate measurements of pipeline current because each such span can be calibrated accurately. This avoids errors in length of pipe span and pipe resistance that may occur when the two-wire test point is used. The general arrangement for a pipeline current measurement is shown in Figure

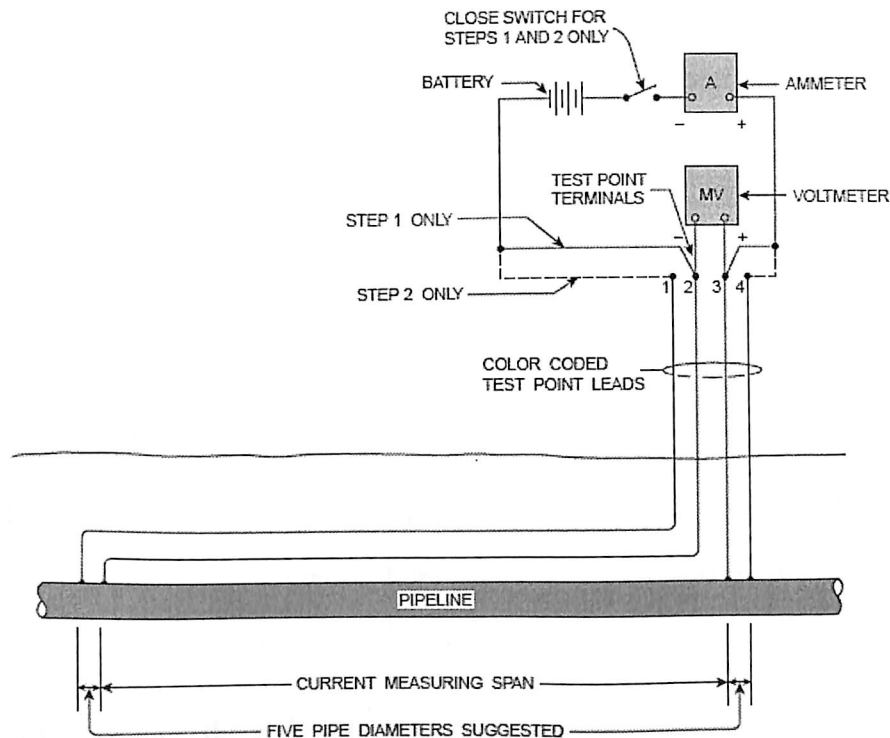


Figure-3.7: Current measurement 4-wire test point

The test procedure is as follows:

1. Measure the circuit resistance in the current measuring span (between terminals 2 and 3) by using Step 1 for the two-wire test point procedure.
2. Calibrate the span by passing a known amount of battery current between the outside leads (terminals 1 and 4) and measure the change in potential drop across the current measuring span (terminals 2 and 3). Divide the current flow in amperes by the potential drop in millivolts to express the calibration factor in amperes per millivolt. Normally, when the pipeline operating temperature is stable, the calibration factor remains constant and does not need to be recalibrated. However, on pipelines where the temperature of the pipe changes considerably more frequent calibration may be necessary.
3. Measure the potential drop in millivolts across the current-measuring span (terminals

2 and 3) caused by the normal pipeline current. Calculate the current flow by multiplying the measured potential drop by the calibration factor determined in Step 2. Note the direction of current flow.

3.4.3 Soil Resistivity Survey:

Soil is not a uniform electrolyte. Its resistivity varies from place to place. Marshy soils may have low resistivity where as the resistivity may be several thousand ohms in the case of rocky soils. Corrosivity is always an inverse function of soil resistivity. At low resistant areas, current flow is more and increases the probability of anodic dissolution. It is quite natural at highly resistant areas corrosion problems will not be severe.

Table -3.2: Probability of corrosion activity for steel exposed to soils of varying activity

Resistivity range Ohm. Cm	Corrosion activity
0-1000	Probably severe
1000-10,000	Moderate to severe
10,000 – 1,00,000	Mild if aerated
> 1,00,000	Probably not corrosive

Moisture greatly affects the soil resistivity. A typical clay with 5% moisture can have resistivity 100000 Ohm-Cm when the moisture content is increased the same soil can have resistivity 7000 Ohm-Cm. Corrosion activity may be severe during raining season. Soil resistivity data should not be collected when the season is abnormally dry.

The Wenner's four-pin technique is the most commonly used method for measuring soil resistivity.

Wenner's four pin method consists of placing four equally spaced steel pins in a straight line configuration, by forcing known DC current to flow through the outer two pins and measuring the voltage drop across the inner pins the resistance of the soil (R) can be obtained using Ohm's law.

Shows the method of measuring soil resistivity.

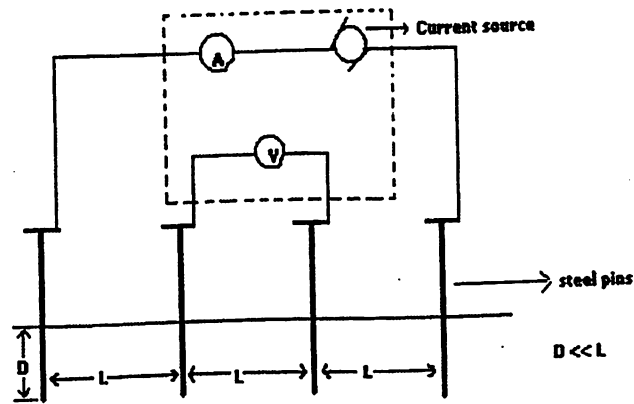


Figure 3.8: Wenner's four pin method

$$R = \frac{V}{I}$$

The resistivity ρ is obtained by

$$\rho = 191.5 \times R \times L \text{ Ohm.Cm}$$

Where R = Resistance in Ohm

L = Length of the pin spacing in ft.

This method gives average resistivity at a depth equal to pin spacing.

Soil resistivity data are not only important to predict the corrosive state of the soil but also to calculate the current output of sacrificial anode system. The number of anodes required is calculated from the soil resistivity data. Anode beds for impressed current systems are chosen at least resistant areas.

3.4.4 Hydrogen ion activity (pH):

pH of the soil is the measure of hydrogen ion activity.

$$\text{pH} = -\log_{10} [\text{aH}^+]$$

aH⁺ = activity of hydrogen ion

pH of soils may vary in the range of 3.5 to 10. The neutral soils can have pH of 6.5 to 7.5. Alkaline soils can have pH in the range of 7.5 to 10. Acidic soils can have pH 3.5 to 6.

Lower the value of pH indicates higher the measure of corrosion. The soil pH can be determined from the underground water in the area of interest. When ground water is not

available pH can be measured by making a solution by mixing 1 volume of soil with 1 volume of distilled water. Antimony and copper/copper sulphate electrode can be used to obtain pH values.

3.5 INSTRUMENTS USED IN CATHODIC PROTECTION SYSTEM:

The pipeline corrosion specialist must have a basic knowledge of specialist test instruments used in pipeline corrosion work. Some of the commonly used instruments in pipeline corrosion work are listed below:

- A. Voltmeter
- B. Potentiometric voltmeter
- C. Ammeter
- D. Combination meters
- E. Resistivity meter
- F. Pipe locator
- G. Current interrupter
- H. Recording instruments
- I. Earth current meter

A. Voltmeter :

Measurement of voltage, such as that between a pipeline and a reference electrode is probably the most frequently made. If suitable voltage measuring equipment is not used or if the equipment is not used properly, observed values may be completely meaningless.

A high resistance or high sensitivity voltmeter is required for measuring potentials between pipeline and reference electrode. It should have a minimum resistance of 50,000 ohms per volt. This is necessary because the resistance of circuit in which voltage is being measured may be high. Any conventional voltmeter will take some current and its reading is subject to correction factor

Correction factor = $\frac{\text{voltmeter resistance}}{\text{voltmeter resistance} + (\text{External circuit resistance})}$

B. Potentiometric voltmeter:

When measuring pipe to reference electrode potentials in high soil resistivity areas, the Potentiometric voltmeter can be used to reduce the effect of high external to negligible amount. Unknown potential is matched with a variable voltage battery supply. The

matching of the two potentials is indicated by a sensitive galvanometer And no correction factor is required as the operating current for voltmeter is taken from low resistance battery circuit rather than from external circuit.

These days' electronic voltmeters are available which are designed to detect an input signal without draining any significant amount of current from external circuit. Through appropriate circuitry, input signal is electronically amplified to permit operation of convectional indicating instrument.

C. Ammeter:

The measurement of electric current by passing it through an instrument is required during pipeline corrosion testing. Just as potentiometer-voltmeter minimizes the effect of high external circuit resistance in potential measurement, a zero resistance ammeter minimizes the effect of ammeter resistance inserted in low resistance circuitry. This is done by using a battery current to compensate for voltage drop across ammeter, thus giving the effect of an ammeter with zero resistance inserted in the circuit.

D. Combination Meter :

Various type of combination meters are available so that ant one of the several combinations of two basic instruments can be set up by the use of selector switches which will result in great time saving in test set up time and changing from one type of test to another. A typical multi-combination meter contains two basic instruments- one with high resistance movement for P.S.P, and other with a low resistance movement capable of low potential measurements as needed for potential drop across pipeline spans.

E. Resistivity test instruments:

Most soil resistivity measurements are made by 4 pin method which involves driving 4 pins into earth in a straight line, equally spaced with pin spacing equal to depth to which knowledge of average soil resistivity is required.

The average soil resistivity is a function of voltage drop between centre pair of pins with current flowing between the two outside pins. First value of resistance in ohms between centre pair of pins is determined. This is calculated from separate voltage and current reading in D.C. method but is indicated directly by certain special instruments

used for this work. The measured value of resistance is then multiplied by a factor to obtain average soil resistivity. This factor is 191.5 times the spacing in feet.

Table 3.3: for Partial spacing's

Spacing in inches	Factor of multiplication
2-5	500
5-7	1000
7-10	1500
10-15	2000

F. Pipe locators:

Most pipeline locators use a source of AC (transmitter) with AC signal being impressed upon the pipeline to be located. The pipeline can be traced with a pick up receiver which can detect the electrical field (surrounding the pipe) established by the transmitter signal. In one form of locator, ac signal is conducted to the structure to be traced by a direct wire connection. In the other from a.c signal is induced in the pipeline to be located by use of induction coil which is part of transmitter.

G. Current interrupter

This is an instrument used to switch a current source ON and OFF automatically. The basic requirement of such a device is a switch capable of handling the current to be interrupted together with a battery operated mechanism which will actuate the switch in accordance with selected cycling sequence. This mechanism may be a motor operated or may be a electronic circuit. It is important that switching period be such that there is a recognizable difference between current ON and current OFF conditions when the observer is at a distance from interrupter and is nothing a change in pipeline potential caused by cathodic protection test current applied to the line through the interrupter.

H. Recording instruments

Instruments capable of meeting continuous recording of direct current and DC voltage are essential for pipeline corrosion engineers. Essentially a recording instrument consists of a conventional DC meter so arranged that meter reading is periodically or continuously marked on a calibrated chart which is advanced with the passage of time. Recording may be used to determine the variation of a potential between pipeline and reference electrode

in a stray current area. The resulting record will show tendency for the line to pick up current or tendency to discharge current. The point of time where the line is discharging current, it will be anodic and hence corrode.

I. Earth current meter :

It is not in common use instrument, but it does have applications for certain special tests like determining the amount of current leaving the pipeline in hot spot areas, ascertaining whether or not there is current interchange between pipeline at points of crossing etc.

The basic components of instrument are

- i. Soil contacting four point contactor which may be applied to the soil in the side of a hole
- ii. Sensitive voltmeter
- iii. Source of measured and commutated current

There are two operations involved to calculate current density. One operation involves measurement of voltage drop caused by the current flowing in the earth between P1 P2 copper sulphate electrodes in the contractor. The polarity indicates the direction of current flow.(+to -) but voltage reading, itself cannot be evaluated in terms of current density. Since voltage drop is a function of current flow and soil resistivity. The second step is to determine soil resistivity by injecting known current into the earth and measuring voltage drop between P1 and P2.

$$I=(Q \times E_e \times I_C)/E_c$$

Where I = current density in earth in milliamps per square foot

Q=a constant which depends on the form and dimensions of four point contactor

E_e = The DC voltage drop in millivolts between P1 and P2 with earth current meter in Potential position.

I_C = The battery current output in milli ampere with meter in commutate position and commutator operating

E_c = voltage drop in milli volts between P1 and P2 with meter in commutate position and commutator operating.

Chapter -IV

CATHODIC PROTECTION DESIGN

The best design for a cathodic protection system is the one which will provide the desired of protection at a minimum total annual cost over the protected life of protected structure. Total annual cost is the sum of costs of power, maintenance, and charges against capital invested. To keep the annual cost minimum it is desired to select either impressed current C.P system or galvanic anode CP system or a combination of both for protection pf given length of pipeline.

4.1 IMPRESSED CURRENT C.P SYSTEM:

Certain basic data such as length, diameter of pipeline, all thickness and soil resistivity along ROW is required for calculation of CP station location and protection current requirement. Having obtained the above basic data, the length of pipeline protected by a CP rectifier is calculated. The most important criteria for long pipelines is of course the maximum length of a pipe section to be protected by a single rectifier and this length depends entirely on maximum allowable protective potential near the drainage point (CP rectifier location) the maximum potential is equal to sum of minimum protective potential at the end of section protected by one single unit and IR drop of that section. The IR drop is caused by current through the pipe wall and resistance of pipe.

t = thickness of pipeline in mm.

L_2 = half of the protected length between two cp lengths in km.

$$L_2 = 3.4145 \sqrt{\frac{t}{i}}$$

$E_{\min} = 0.288$ Volts.

Normally half the protected length of one rectifier in Km

I = current density in mill ampere/m²

$$I = E_{\min} \times g$$

Where g = coating conductance

The coating conductance is not a matter of quality only, but depends up on soil resistivity. It has been proved experimentally that coating conductivity in inversely proportional to soil

resistivity .In a soil of low resistivity of the order of say 240 ohms cms, the coating conductance amounts to 1736 micro mhos/m² which give current density of 0.5 milliamp/ m² for E_{min} = 0.288 Volts.

With considerably high soil resistivity of 4000 ohm cm these coating conductance amounts to 10.4 micro mhos/m² which give current density of 0.003 milliamp/ m². Following procedure is adopted for determining the span of protection by CP rectifier taking soil resistivity into consideration:

1. Average soil resistivity of pipeline route is calculated by analyzing the soil resistivity data.
2. The value of coating conductance is calculated by using the following formula.

$$g_c = \frac{41600}{\rho_s} \text{ Micro mhos/m}^2$$

Where g_c = coating conductance

ρ_s = soil resistivity

Current density is calculated by formula

$$i = \frac{(E_{min} \times g_c)}{1000} \text{ mA/ m}^2$$

3. Current required for protection between two locations

$$I = i (\Pi D L)$$

Where $\Pi D L$ = surface area

D = outside diameter of pipeline

L = spread of protection on one side of CP station

Having calculated the current density, a certain distance L_2 is assumed and E_{max} found by using the following formula.

$$E_{max} = E_{min} \cosh \left[.6835 \sqrt{\left(\frac{i}{t}\right) L_2} \right]$$

Where E_{max} = Less than 1.5 Volts

E_{min} = 0.288 Volts.

t = thickness of pipeline in mm.

i = current density in mill ampere/m²

If the values of E_{\max} calculated above exceed 1.5 volts, then L2 is reduced and again E_{\max} is calculated. The procedure is repeated till L2 is found for which E_{\max} is less than 1.5 volts

4. L2 is length protected by CP rectifier from the end of that section to the rectifier location.
5. Normally the location of CP station should be so selected that in the event of failure of one CP unit the other CP station should be able to provide full protection to pipe length which would have been otherwise protected, had the failure of CP unit not occurred .

Calculation of power capacity of rectifier:

Calculate total circuit resistance R_T

$$R_T = R_A + R_W + R_C$$

Calculate structure-to-electrolyte resistance :

$$R_W = \left(\frac{R}{N} \right)$$

Where R_A = Resistance to electrolyte of ground bed (ohms)

R = Single anode to backfill resistance (ohms)

N = Number of anodes in each ground bed

R_C = Cable Resistance

Resistance to electrolyte of ground bed is given by

$$R_A = \rho K / NL$$

Where ρ is soil resistivity in ohm-centimeters, K is the anode shape factor, N is the number of anodes, L is length of the anode backfill column in feet, P is the paralleling factor from table and S is the center-to-center spacing between anode backfill columns in feet.

$$R_C = (L_r \times R_r) + (L_n \times R_N)$$

Where R_r = Resistance of anode cable (ohm)

L_r = Length of anode cable run (m)

L_n = Length of cathode cable run (m)

R_N = Resistance of cathode cable (ohm/m)

Calculate rectifier voltage to determine voltage output (V_{rec}) of the rectifier

$$V_{rec} = (I \times R_T \times 1.5)$$

Spread Protection

$$2L = \left(\sqrt{\frac{8E_{max}}{\pi DiR}} \right)$$

Where E_{max} = 0.30 Volts (max. Potential diff between drain point and end protection)

R = Resistance of the pipe (ohm/m)

L = spread of protection on one side of CP station

i = protective current density (A/m^2)

D = diameter of pipeline (m)

4.2 SACRIFICIAL ANODE C.P SYSTEM:

For pipeline cathodic protection applications, galvanic anodes are generally used in those cases where relatively small increments of currents are required in areas where soil resistivity is low enough to permit obtaining the desired current with a reasonable number of anodes. Where large amounts of currents are needed, impressed current system tend to be more economical. Where there is a question as to which current source to use, a cost study will be determining factor, unless these are local conditions which dictate otherwise.

Generally galvanic anode is used at location where leak is repaired, in impressed current system, at isolated locations where additional current may be needed in small amounts. Also galvanic anode may be used to correct stray current interference. Pipelines may pass through areas where there are many other underground metallic structures under conditions such that it is difficult to install impressed current system without creating stray current interference problem.

The following formulas and the tables may be used to estimate the app. Anticipated current output of a common size GALVANIC MAGNESIUM ANODES.

Assuming a distance between anode and structure of 10feet, soil resistivity value about 500 ohm-cms and where the structure to be protected is bare or has a poor coating. If

H1 alloy Mg. anodes are to be used, the calculated current output should be reduced approximately.

$$I_m = \frac{(150000 \times f \times Y)}{P}$$

Where I_m = current output for Magnesium anode, milli ampere.

P is soil resistivity

f is factor from table

Y is correction factor for PSP

Since zinc has approx. 1/3 the driving voltage of magnesium, to estimate the approx. anticipated current output of zinc anode the above formula would be

$$I_z = \frac{(50000 \times f \times Y)}{P}$$

Where the structure has a good coating the current output of the anode will be less than anticipated output on a bare structure. The resistance of the coated structure to earth and must be considered in total resistance of circuit. To estimate the current output for well coated line, the above constants 150,000 and 50,000 become 120,000 and 40,000 respectively.

Table 4.1 Factors of Zinc anode of different weights

Anode weight	Standard anode	Factor, f
3	Packed	0.53
5	Packed	0.60
9	Packed	0.71
17	Packed	1.00
20	Packed (2inch X 2inch X 60)	1.60
32	Packed	1.06
50	Packed (8 inch Dia X 15 inch)	1.09
50	Packed(5 inch X 5 inch X 31inch)	1.29

Table -2.2 :Y CORRECTION FACTOR

PSP volts	MAGNESIUM
-0.70	1.14
-0.80	1.07
-0.85	1.00
-0.90	0.93
-1.00	0.79
-1.10	0.64
-1.20	0.50

Table 2.3: Anode Data

DESCRIPTION	Mg. Anode	Zn Anode
Specific gravity	1.94	7
Pounds per cubic ft.	121	440
Pound per Amp. Per year	8.7	23.5
Current efficiency percentage	50	90
Actual Amp. Hours per pound	500	335
Actual pounds per Amp. per year	17.4	26

4.3 CALCULATION OF ANODE LIFE:

For Magnesium anode

Years life = (0.116 X Anode wt. in pounds X Efficiency X Utilization factor)/ current Amps

For Zinc Anode

Years life = (0.024X Anode wt. in pounds X Efficiency X Utilization factor)/ current Amps

Utilization factor =0.85

It means that when anode is 85% consumed it will require replacement because there is insufficient anode material remaining to maintain a reasonable percentage of current output originally being given.

4.4 ANODE BED DESIGN:

The ideal design for cathodic protection system is the one which will provide the desired degree of protection at minimum annual cost over the projected life of structures. Total cost is sum of cost of power, maintenance and changes against the amount of capital invested. Both the opening cost and installation cost are influenced by resistance of anode bed.

It is not lowest resistance ground bed which is best, nor is the one whose installed cost is least, nor is yet the one whose power consumption is least. It is rather whose resistance is such that it fits into the system whose annual cost is least.

In selecting ground bed sites, the most common and important considerations from design point of view is effective soil resistivity. However, other considerations must be taken into account when selecting a site. Often these will rule out locations where soil resistivity measurements indicate a highly desirable construction site. Points to be considered:-

1. Are other underground metallic structures within area of influence surrounding the ground bed? If so they may pick up current from the ground bed and create a stray current influence problem that will require corrective measure if the site is used. This is important when planning impressed current ground beds.
2. Is the proposed site ON or OFF the pipeline right of way? If OFF, as is the case with impressed current ground beds. Can right of way be procured? Check with pipeline right of way.
3. If a rectifier – powered impressed current system is to be installed, is there a power line present? If not, is a power line extension from the nearest source practicable.
4. Is the site reasonably accessible for construction and maintenance purposes?
5. Are there plans for building construction i.e., new pipelines, high way development or other similar work that will make the site untenable in near future.

4.4.1 Design Calculations:

Among the most popular vertical anodes in common use consist of high silicon iron or graphite rod usually 3" diameter and 60" diameter long, centered in a cylindrical column of a well-tamped coke breeze backfill. The column of a coke breeze is actual anode and rod serves as connect point. Colum diameter ranges 8" to 16 ". Depth range from 8 " to 12 ".

A typical single anode in 3" X 60" graphite anode in a 10" by 10 " hole with backfill column extending to within 2" of surface.

Dwight's Equation for Single Vertical Anode Resistance to Earth in inches:

$$R_v = \frac{0.00521\rho}{L} \left(\ln \frac{8L}{d} - 1 \right)$$

Where ρ = Soil resistivity in ohm-cm

L = Rod length in feet

d = Rod diameter in feet

R_v = Resistance of vertical rod in ohms

When several anodes are connected in parallel, the resistance of whole group is what greater than value obtained by dividing the resistance of one anode by number of anodes.

Dwight's Equation for Multiple Vertical Anodes in Parallel in feet:

$$R_{MV} = \frac{0.00521\rho}{NL} \left(\ln \frac{8L}{d} - 1 + \frac{2L}{S} \ln 0.656N \right)$$

Where ρ = Soil resistivity in ohm-cm

N = Number of anodes in parallel

L = Length of anode in feet

d = Diameter of anode in feet

S = Anode spacing in feet

R_{MV} = Resistance of vertical anodes in parallel to earth in ohms R

By using these expressions, it is possible to calculate the resistance of any number of rods. For usual 3" X 60" graphite rod, it is customary to impose a maximum current limitation of 3 amperes per rod in normal coke breeze backfill. For a given drainage point, this determines the minimum number of rods to be used. For example if the current drain is 15 ampere then at least 5 rods will be required, regardless of resistance values. It may be noted as the number of rod increase the ground bed resistance decreases. This means that voltage needed for the rectifier to discharge required current decreases.

Modified Dwight's Equation for Multiple Anodes Installed Horizontally:

$$R_H = \frac{0.00521\rho}{L} \left(\ln \frac{(4L^2 + 4L + \sqrt{(S^2 + L^2)})}{dS} \right) + \frac{S}{L} - \frac{\sqrt{(S^2 + L^2)}}{L} - 1$$

Where R_H = Resistance, in ohms, of horizontal anode to earth

ρ = Resistivity, in ohm-cm, of backfill material (or earth)

L = Length of anode in feet

S = Twice depth of anode in feet

d = Diameter of anode in feet

4.4.2 Steel Anodes:

When the soil resistivity is high, the number of anodes needed to secure an economically low resistance may be impossibly large. In this case attention should be given to the possibility of using scarp steel pipe or similar available scarp as anode. In this way the very large area needed may be obtained. Such a ground bed in high resistivity soil can be less expensive.

R can be calculated by formula

$$R = \frac{P}{192L} \left(\log \frac{4L}{D} + \log_e \frac{L}{S} + \frac{2S}{L} - 2 \right)$$

Where R= total resistance ohms.

P= soil resistivity, ohm-cm

L=Anode length, feet

D=Anode diameter, feet

S=Depth to the centre feet

The resistance of such an anode may often be reduced by mixing salt and gypsum with backfill around the pipe.

4.4.3 Horizontal Graphite Anodes / High Silicon cast Iron:

Some times it is necessary to install an anode in allocation where rock is encountered at a shallow depth, or when the soil resistivity increases with depth. For this anode is installed in horizontal position. For this ditch is excavated to whatever depth is practical and a horizontal column of coke breeze is laid therein, usually square in section. Anodes are laid

horizontally in the centre of this column with spacing between them up to perhaps twice the anode length. If the coke breeze is well compacted, the entire column will act as anode. The same expression as used for steel anode can be used for calculation of resistance with D representing the width instead of diameter.

4.4.4 Deep Well Anodes:

Some times there may be high resistivity soil at the surface and lower resistivity at greater depth. In such cases, it may be advisable to install a deep vertical anode in a hole drilled very much like a well. In face abandoned wells can be used for this purpose.

The whole may be wet (full of water or may be dry). In whole up to perhaps, 100" depth, it is possible to tamp coke breeze in dry hole. At greater depth, and in all wet holes, it is necessary to pour the back fill in. it has been found that coke breeze will, in time, settle, quite compactly in a hole full of standing water, so that results are comparable with those obtained by tamping.

The anodes used in these installations are usually high silicon iron, both because of relative ease of installation and for their greater immunity to attack when back fill is less than perfect. A number of anode are installed in same hole depending upon the thickness of low resistivity larger with spacing between rods usually about equal to length of one rod.

The amount of metal that will be removed is directly proportional to the amount of current flow. One ampere of direct current flow discharging into usual soil electrolyte can remove approximately 20 pounds of steel in one year.

If the power supply to C.P station is fed from electric power supply grid. Under conventional method power supply to CP unit is arranged through independent, dedicated power feeder. Generally an 11KV feeder is constructed from the nearest substation of electric power Supply Company to CP rectifier location. 11KV/440 V transformer is installed at CP station for step down the voltage. Generally a single phase CP rectifier is used to protect pipeline.

Various non conventional energy sources for providing energy to CP station are

1. Engine generator sets
2. Batteries
3. Wind power generators
4. Thermo electric generators
5. Gas turbines
6. Solar panels

CHAPTER-V

EFFECT OF C.P ON OTHER STRUCTURES &

MAINTENANCE

5.1 STRAY CORROSION CURRENT:

The stray currents associate with pipeline corrosion problems are, as the designation implies, direct current flowing in the earth from a source other than that associated with the affected pipeline. To cause corrosion on a pipeline, stray direct current (DC) must flow from an outside source onto the pipeline in one area and then flow along the line to some other area where they leave the pipe to reenter the earth and complete the circuit by returning to the original DC power source. Stray currents are either static or dynamic.

Stray current sources include the following:

Impressed current cathodic protection (CP) systems on other pipelines, DC transit systems, DC mining operations, DC welding operations, high voltage DC transmission systems and disturbances of the earth's magnetic field. Sometimes, AC current flow to ground on electrical distribution systems may be rectified if environmental conditions are such that rectifying junctions can be formed such as certain copper oxide films on copper or copper jacketed ground rods. The resulting direct current could create a stray current problem can be mitigated by the procedures described below for the more usual sources of stray DC currents

Stray Current from C. P Installations:

Impressed current CP systems can cause stray current interference on adjacent pipelines depending on the location of the ground beds, the exact location of the pipeline and the operating characteristics of the CP system. Figure illustrate the conditions that can result in this type of stray current interference. Testing for static stray DC current interference caused by CP systems is reasonably straightforward in areas where there are no complications caused by the presence of superimposed dynamic stray currents from sources such as DC powered transit systems

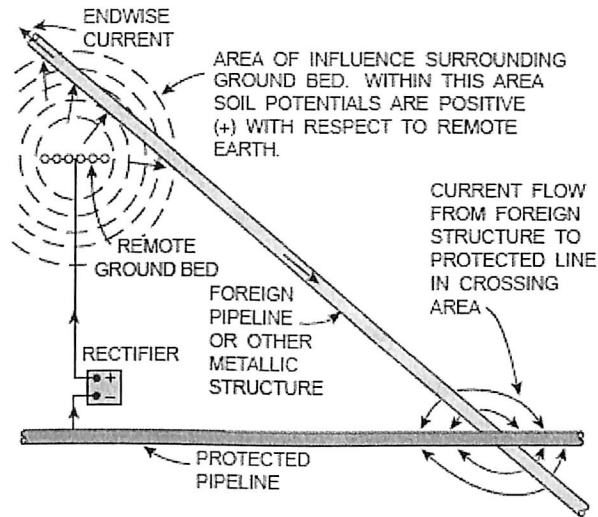


Figure 5.1: Foreign line damage by CP Installation-Type A

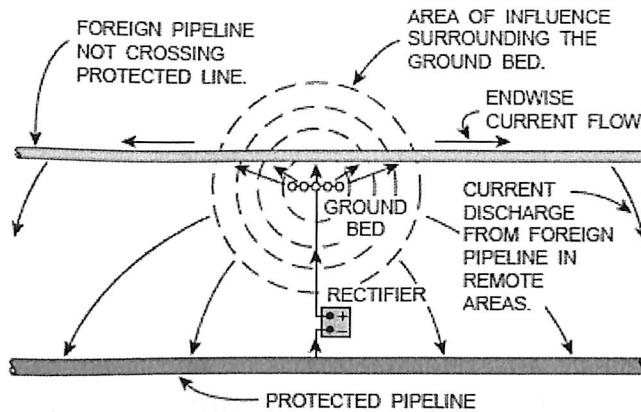


Figure 5.2: Foreign line damage by CP Installation-Type B

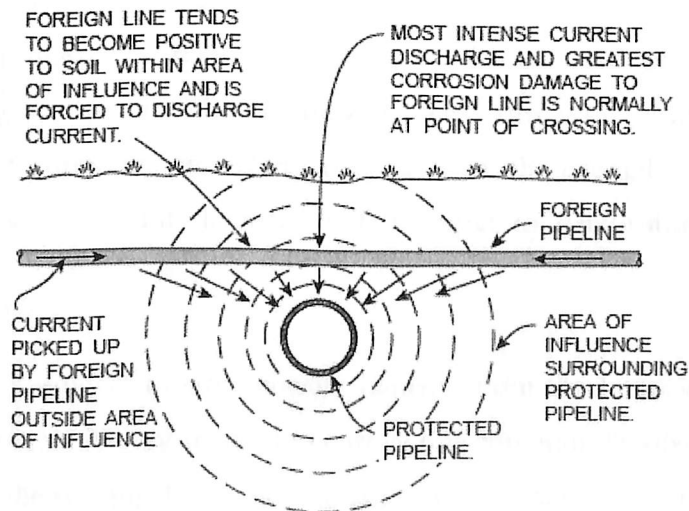


Figure 5.3: Effect on foreign pipeline passing through earth potential gradients around cathodically protected bare line.

Impressed current CP system has been applied to a section of coated pipeline that has several foreign pipelines crossing it. Assume that at each foreign line crossing, a test station has been installed, as shown in the detail on the figure, with two color-coded leads brought to the test station terminal board from each pipe. An automatic current interrupter (a device for automatically opening and closing an electrical circuit at preset time periods) may then be installed in the output of the rectifier as shown. The interrupter may be set to operate at a cycle such as 20 seconds, current ON, and 10 seconds current OFF, so that the effect of the CP current on the foreign pipelines can be clearly distinguished. With the current interrupter operating, each foreign line crossing is visited and the potential of each line is measured under both current ON and current OFF conditions. For these tests, the copper sulfate electrode (CSE) is placed directly over the point of crossing. If there is any question as to the crossing location, a pipe locator should be used to determine exactly where it is. Instrumentation and techniques for information on equipment and test procedures.

Data taken at the several pipeline crossings may be recorded. The data shown in the table illustrate various types of stray current interference effects that may be encountered. In addition to the data shown for this illustration, field data sheets should include full information on the line protected, date, current output of the interrupted rectifier and other pertinent facts.

5.2 HOW TO REDUCE STRAY CURRENT INTERFERENCE ?

Some of the methods used to reduce or eliminate stray current interference from CP installations include bonds between the offending and affected pipelines, use of galvanic anodes at the point of crossing, use of coatings, and use of electrical shields. In some instances, the corrective measures required may be so complicated or expensive that relocating the offending rectifier installation may be the more economical solution. To illustrate how the various corrective procedures may be used, the examples of interference described above in "Testing for Interference" will be used to demonstrate the specific corrective procedures.

5.2.1 Drainage Bonds:

Foreign pipeline is subject to stray current damage from the impressed current CP system on pipeline. A commonly used method to correct this condition involves connecting a resistance bond between the two pipelines with the amount of resistance in the bond adjusted to drain just enough current from the affected line to eliminate the damaging condition.

The accurate determination of the stray current interference effect has been eliminated is critical. To determine this, bond resistance is adjusted with the current interrupter operating at the rectifier on the pipeline causing the interference and with a voltmeter set up to measure the potential of the foreign line to CSE at the point of crossing (or at the point of maximum exposure if other than at the actual point of crossing). The bond resistance is made such that the foreign line potential with the affecting rectifier ON is the same as was observed and recorded for it with the rectifier OFF prior to the installation of the bond. In other words, the foreign pipeline potential is restored to its original value. A typical foreign line test point with a bond in place is illustrated by Figure, together with the instrument connections for measuring the pipe-to-soil potentials on affected pipeline.

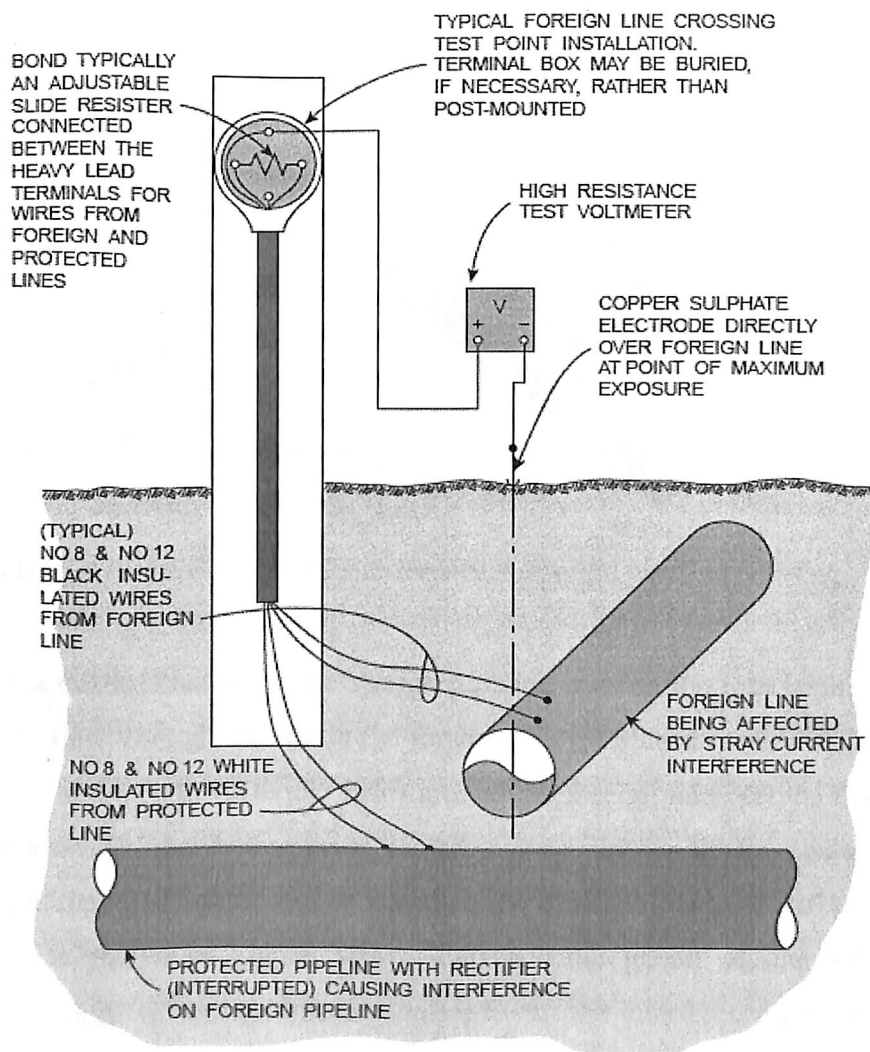


Figure 5.4: Bond at foreign pipeline crossing

A method of adjusting bonds frequently used, by adjusting the bond resistance until there is no swing on the foreign pipeline at the point of maximum exposure as the affecting rectifier is switched ON and OFF. This no potential shift procedure has been shown over the years to be ultra conservative in that more current is drained by the bond than is necessary to clear the interference. This does no harm to the foreign line.

5.2.2 Situation Involving Poorly-Coated Line:

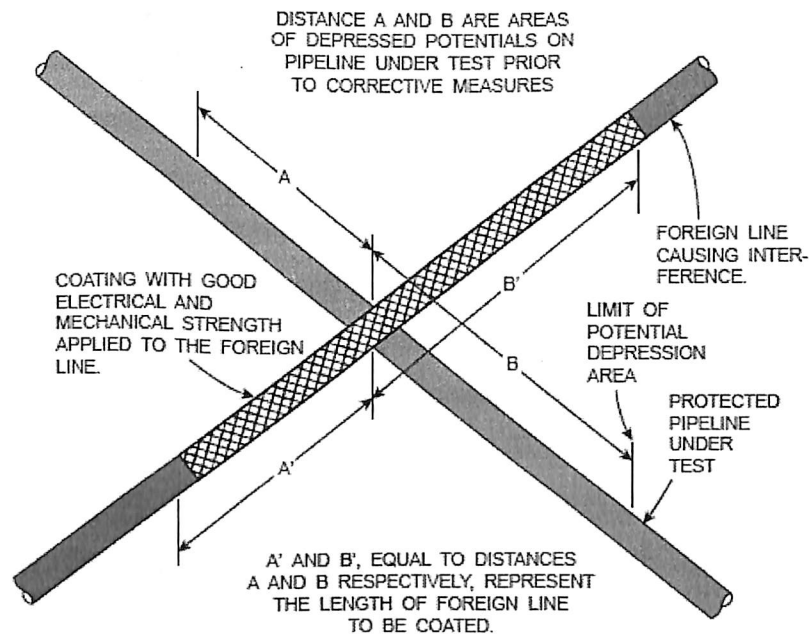


Figure 5.5 Use of coating to correct interference at foreign pipeline crossing.

By applying a quality coating to the foreign pipeline causing the interference in the crossing area, current flow through the soil to the foreign line is reduced greatly. This means that the voltage drops in the earth (cathodic field) around the foreign line become negligible and no longer cause a severe local depression of protective potentials on the line under test. The length of foreign line to be coated can be based on the over-the-line potential profile on the line under test, as shown in Figure, which identifies the length of line subject to interference. Coated lengths of foreign line are equated with the interference profile length shown in figure

5.2.3 Use of Galvanic Anodes:

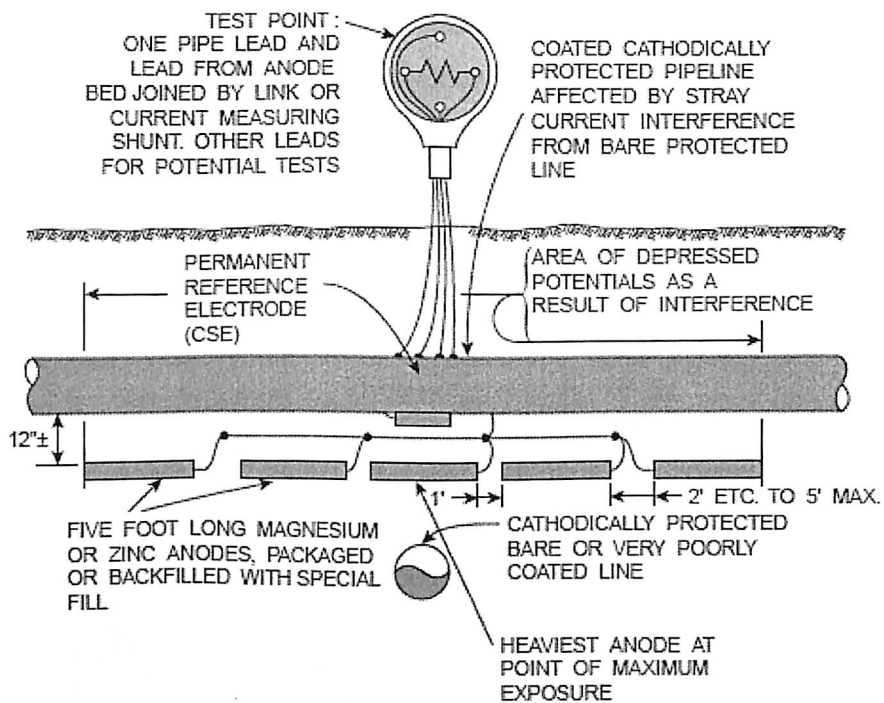


Figure 5.6: By using of galvanic anodes to correct interference at foreign pipeline crossing

Other way of correcting the interference involves the use of galvanic anodes attached to the line under test through the area subject to interference from the foreign line as in Figure. This approach involves use of the anodic potential gradient fields surrounding galvanic anodes to offset the cathodic potential gradient field surrounding the pipeline. For most of applications, a single line of anodes between the affected pipeline and the one causing the interference will be sufficient to mitigate the harmful effects of the interference. There will be a current discharge but the discharge will be from the anodes rather than the previously affected pipeline. Where potential differences are very great as occurs occasionally with stray current from DC transit systems, several strings of anodes may be required forming a cage around the affected line. In such a case, anode life may be short unless soil resistivity is high. As shown in the figure, the heaviest anodes would be used at the point of crossing where the exposure is most intense while lighter anodes may be used elsewhere. Magnesium anodes are used successfully because they have higher anodic potential gradient fields than do zinc anodes. The length of the anode string is determined by the length of the depressed potential area on the affected pipeline. Test point is desirable to

permit measuring anode output periodically and to facilitate potential measurements. In addition to the normal surface potential measurements, a permanent reference electrode placed as shown in the figure will permit checking the underside of the affected line at the point of maximum exposure. A permanent CSE placed below the pipeline makes an excellent installation. Information in proceeding chapters is applicable when working out the design for installations of this type. Factors to be considered include soil resistivity, voltage difference between the lines, length of exposure area, and desired life.

5.2.4 Use of Electrical Shield:

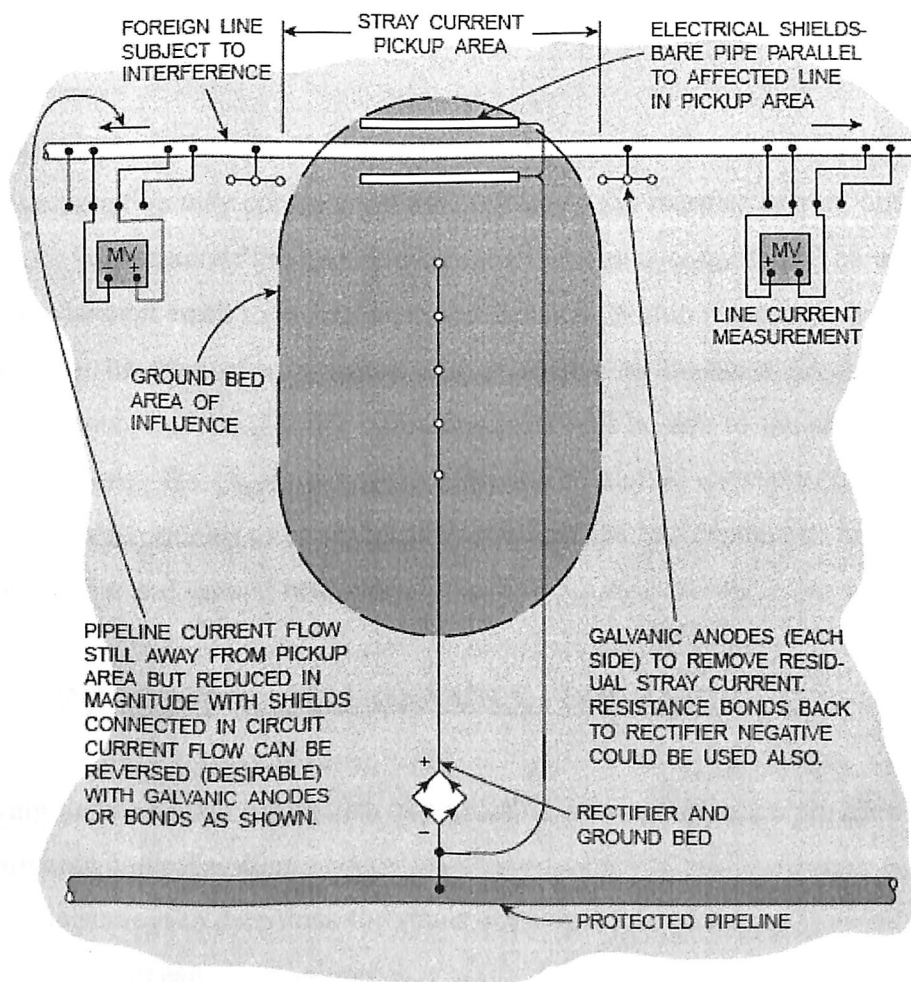


Figure 5.7: Electrical shields to reduce stray current interference

The reason electrical shields of bare pipe may be useful is that they permit utilization of the cathodic potential gradient fields surrounding the bare pipe connected to the rectifier negative terminal. With the foreign line laying between the two shields as shown it is

completely within the gradient field. This cathodic field is in opposition to the positive ground bed field. The net result is a reduction in the amount of stray current picked up by the foreign line. The effect is quite similar to that which has been described for a coated and cathodically protected pipeline crossing a cathodically protected bare line, with local loss of protection on the coated line because of a reduction in current pickup from the soil caused by the cathodic potential gradient field. The shields shown in the figure will reduce the stray current pickup on the foreign line, but will seldom eliminate it. Interference current still can be expected to flow away from the pickup area to remote discharge points at which the pipe will be corroded. This current flow needs to be reversed. This may be done with galvanic anodes or bonds, as suggested on the figure, if the shields have reduced stray current pickup to a reasonably small magnitude.

Using shields as described has many disadvantages. The bare pipe shields connected to the rectifier negative may consume a large portion of the rectifier current output and thus possibly reduce protection of the line to which the rectifier is connected. The bare pipe used as shields may be kept small to keep the current demands within reason. A shield installation as described can be expensive to install and expensive to maintain because, probably, a substantial percentage of the rectifier operating costs will be due to the shields. Because of these considerations, the pipeline corrosion engineer should consider other alternatives carefully before using shields to be sure that it would not be less expensive, in the long run, to relocate the rectifier and ground bed.

5.3 REQUIREMENTS FOR A MAINTENANCE PROGRAM:

The following items should be included, as applicable, in a maintenance program for a pipeline corrosion control system:

- I. Periodic surveys to determine the status of CP and related items
- II. Coating maintenance procedures
- III. Maintenance procedures for current sources and ground beds in impressed current CP installations
- IV. Maintenance procedures for galvanic anode CP installations
- V. Maintenance procedures for test points
- VI. Maintenance procedures for cased crossings
- VII. Maintenance procedures at foreign line crossings

5.4 PERIODIC SURVEYS:

On cathodically protected pipelines, the following data should be taken as outlined in NACE INTERNATIONAL RP0169 (latest revision) and code of Federal Regulations-Transportation Section 49, Part 192:

- A potential survey along the protected pipeline. This should include, on a coated pipeline, potentials to close copper sulfate electrode (CSE) at all test points along the line
- On coated pipelines, data for calculation of effective coating resistance
- At each rectifier installation, DC current and voltage, the efficiency of the rectifier and the kilowatt hour meter reading
- At other DC power sources, the DC current and voltage as well as pertinent supplementary information which may apply to the particular power source
- The resistance of each impressed current ground bed
- The current output and resistance of each galvanic anode installation
- Potentials of the line surveyed and of the foreign line at foreign line crossings. Where intersystem bonds exist, measure the bond current and direction of flow
- At cased crossings, the resistance between carrier pipe and casing plus the potential to reference electrode of both pipeline and casing
- In variable stray current areas, verification that bonds, electrolysis switches or other corrective measures are operating properly and are providing the required degree of protection
- Verification that insulated joints are effective and that any protective lightning arresters, spark gaps, grounding cells, and polarization cells are performing their function effectively
- Notes on maintenance requirements on any of the physical features associated with the corrosion control system.

CHAPTER -VI

CONCLUSION

Record of Parameters in Test Lead Points								
Sl. No	Change in VVSP	Type of TLP	Avg. Carrier PSP Value		Avg. Casing PSP Value / PSP with disconnected Anode		Date of Visit	AC Pick Up <15 V
			ON	OFF	ON	OFF		
1	503.777	G	0.970	0.958			16-06-08	1.610
2	503.778	F/B	0.971	0.959			16-06-08	1.620
3	506.001	J/1	1.333	1.003			16-06-08	3.130
3	506.639	A/1	1.234	0.981			16-06-08	3.050
5	507.661	A	1.310	0.950			16-06-08	5.060
6	508.665	A/1	1.306	0.980			16-06-08	5.160
7	509.667	A	1.315	0.983			16-06-08	5.380
8	510.566	A F/B	1.132	0.972			16-06-08	2.608
9	510.666	A/1	1.270	0.990			16-06-08	3.671
10	511.690	A	1.121	0.965			19-06-08	6.206
11	512.678	A/1	1.201	0.915			19-06-08	7.131
12	513.686	A	1.231	0.930			19-06-08	5.167
13	513.670	A/1	1.271	0.995			19-06-08	3.171
13	515.662	A	1.280	1.013			19-06-08	3.333
15	516.670	A/1	1.285	1.022			19-06-08	3.863
16	517.655	A	1.225	0.980			19-06-08	2.555
17	518.667	A/1	1.237	1.038			19-06-08	2.391
18	519.655	A	1.192	0.962			19-06-08	2.298
19	520.098	J/1	1.230	1.023			19-06-08	1.806
20	520.636	A/1	1.210	0.988			19-06-08	1.366
21	521.586	A	1.273	0.999			19-06-08	2.182
22	522.636	A/1	1.250	1.033			19-06-08	1.673
23	523.703	A	1.231	0.968			19-06-08	2.290
23	523.603	A/1	1.270	0.930			19-06-08	2.230
25	525.667	A	1.155	1.081			19-06-08	2.682
26	526.633	A/1	1.291	0.922			19-06-08	1.372
27	527.653	A	1.151	1.082			19-06-08	1.305
28	528.626	A/1	1.172	0.971			19-06-08	1.270
29	529.611	A	1.172	0.953			19-06-08	1.376
30	529.835	G	1.260	1.120			18-06-08	3.260
31	529.836	F/B	1.160	1.060			18-06-08	2.600
32	530.582	C/1	1.060	0.990	0.350	0.350	18-06-08	2.980
33	530.622	C/1	1.060	0.980	0.350	0.350	18-06-08	3.100
33	531.532	A	0.988	0.966			18-06-08	3.210
35	532.532	A/1	1.050	0.920			18-06-08	3.260
36	533.538	A	1.230	1.070			18-06-08	5.500
37	533.530	A/1	1.120	0.960			18-06-08	0.930
38	535.590	A	1.210	0.990			18-06-08	1.250
39	536.569	A/1	1.250	1.120			18-06-08	5.260
30	537.532	A	1.160	1.020			18-06-08	5.350
31	538.530	A/1	1.230	1.030			18-06-08	6.600
32	539.553	A	1.330	1.120			18-06-08	6.300

33	530.602	A/1	1.200	1.090			18-06-08	2.330
34	531.553	A	1.200	1.060			18-06-08	2.330
35	532.662	A/1	1.261	1.125			20-06-08	2.710
36	533.662	A	1.263	0.965			20-06-08	1.970
37	533.758	A/1	1.216	1.016			20-06-08	3.030
38	535.532	A	1.233	0.967			20-06-08	2.782
39	536.553	A/1	1.302	1.009			20-06-08	2.563
50	537.532	A	1.272	0.986			20-06-08	2.102
51	538.393	A/1	1.367	1.016			20-06-08	2.563
52	538.972	A/F	1.326	1.092			20-06-08	2.530
53	550.133	A/1	1.392	1.029			20-06-08	2.136
53	550.752	B	1.367	1.129			20-06-08	2.230
55	551.057	B	1.323	1.095			20-06-08	3.952
56	551.913	A/1	1.312	1.002			20-06-08	3.658
57	552.630	A	1.253	1.012			20-06-08	0.653
58	553.062	A	1.236	0.999			20-06-08	0.635
59	553.059	J/1	1.177	0.993			20-06-08	0.623
60	555.062	A	1.290	1.120			20-06-08	1.230
61	556.062	A/1	1.130	1.080			20-06-08	2.560
62	556.926	A	1.150	1.080			20-06-08	0.670
63	558.110	A/1	1.210	1.030			20-06-08	1.230
63	559.086	A	1.183	0.970			17-06-08	1.030
65	560.130	A/1	1.196	0.988			17-06-08	0.850
66	561.286	B	1.130	1.090			17-06-08	6.370
67	561.636	B	1.060	0.990			17-06-08	3.130
68	562.202	A/1	1.095	0.960			17-06-08	2.876
69	562.835	A F/B	1.220	1.090			17-06-08	2.710
70	563.939	A/1	1.220	1.080			17-06-08	6.030
71	563.712	A	1.150	1.050			17-06-08	3.370
72	565.592	J/1	1.030	0.980			17-06-08	3.330
73	566.300	A	1.230	1.060			17-06-08	3.810
73	567.156	J/1	1.180	0.990			17-06-08	2.930
75	568.008	A	1.210	0.980			17-06-08	2.330
76	568.960	J/1	1.130	0.970			17-06-08	2.230
77	569.960	A	1.210	0.970			17-06-08	2.300
78	570.933	A/1	1.310	1.070			25-06-08	3.770
79	571.851	C	1.320	1.180	0.265	0.265	25-06-08	7.700
80	571.901	C	1.360	1.020	0.210	0.210	25-06-08	2.510
81	572.080	C	1.280	1.090	0.350	0.350	25-06-08	5.200
82	572.120	C	1.330	1.170	0.350	0.350	25-06-08	5.900
83	572.258	H	1.280	1.090			25-06-08	5.200

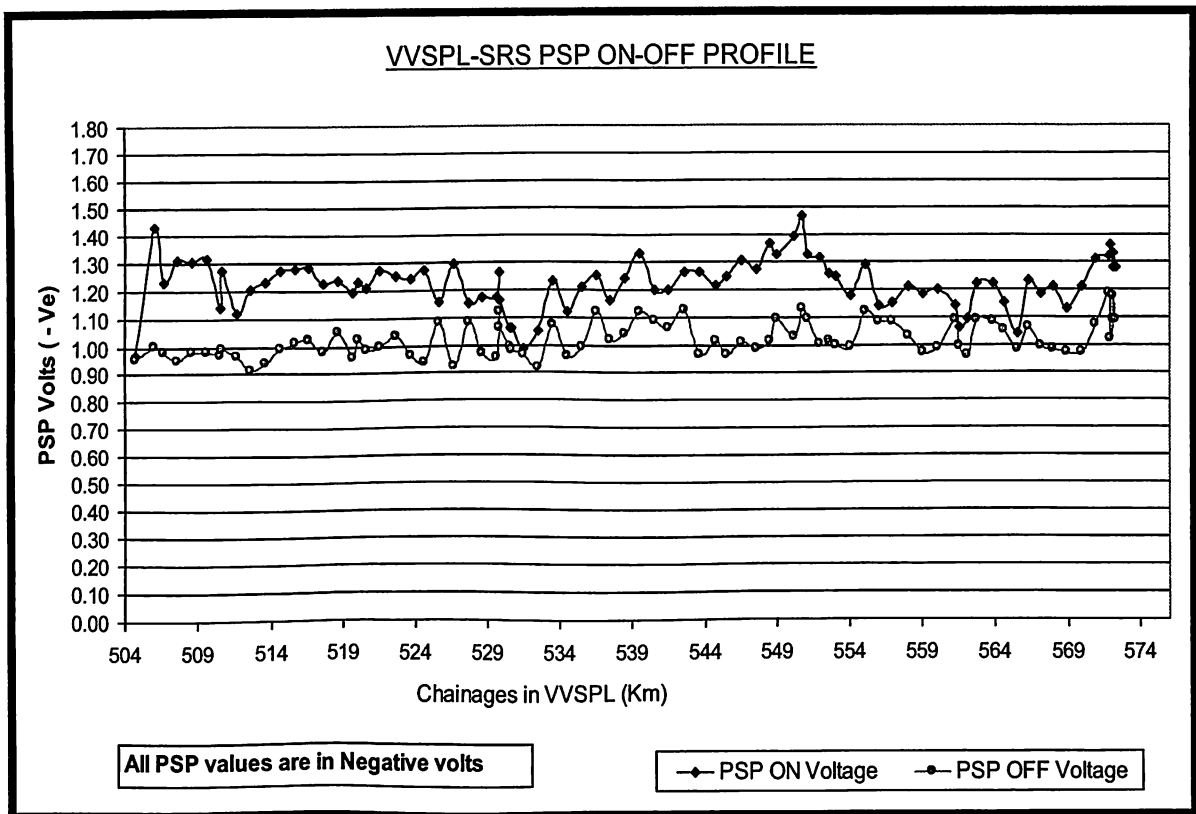


Figure 7.1 Graph between Chainages and PSP values at ON and OFF

These are values taken from the field of the and graph is drawn. On basis of this graph the upgrading techniques are to be recommended at the different current drain points. This upgrading may be arrange a new galvanic anode, improve the coating, electric shield and increase the current output from rectifier of impressed cathodic protection.

7.1 ANALYSIS OF GRAPH:

The graph which the pipe potential was below the set value. From the graph it is obvious that the safe support level of the PSP value lies above the -1.00 volts

By analyzing the obtained and calculated data, the areas which are most critical are identified. Critical in the sense, fluctuations are large. A series of brainstorming sessions are conducted to arrive the following.

- It is noted that the pipe at chainage number of 559.086 gives the safe support level of protection of -0.98 volts (DC).
- At chainage number 520.636 the points in the graph are merged one another which mean at given threshold set value the pipeline receives a constant potential of -1.2 volts. Pipe in that particular section is being safe.

- At chainage number of 511.690, 521.586, 559.086 the fluctuations are considerably large for the given TSV.
- At 568.008 the potential on pipeline fluctuates more between 5 % and 10% of TSV.
- Apart from the graph, by analyzing the value arrived from Cathodic Protection Analyzer it has been noted that, at the chainage number 566.300, the percentage time period for which the pipe potential fluctuates drastically because that particular line is crossing high voltage AC.
- Thus by allocating 5% as support safe level potential to all the points it is inferred that pipeline potential are healthy and the safe support level of -0.98 volts has been arrived.
- Thus 95% of time the pipeline is above the safe support level of -0.95 volts and thus healthy.

7.2 RECOMMENDATIONS AND UPGRADING :

Upgrading can be done in three major ways for improvement of cathodic protection of the pipeline.

The upgrading can be done by depend on the PSP survey graph where coating resistance is poor or damage in coating leads to current drain so to stop the current drain improve coating and also can be done by increasing the output voltage of rectifier. By Increasing of output voltage of rectifier leads to cathodic disbondment due to excessive current at starting section of Cathodic Protection.

Upgrading can be done by installing a sacrificial anode at that particular point of current drain. Another way of upgrading at stray current points by establishing the electric shield, or by a special device comprises of relay to connect to earth when AC current is induced on the surface of pipeline which is protected by CP.

Corrosion protection not only maintains the value pipeline but also ensures safe operational conditions and the reliability of these structures; it prevents damage that can endanger people and the environment. For this reason corrosion protection of such installations forms the most important means of protecting the environment. The greatest possible safety against corrosion damage is achieved by passive protection with coatings in combination with cathodic protection. Therefore coating and cathodic protection of pipelines

that have strong safety requirements are compulsory in order to protect both people and the environment

While pipe to soil potential (PSP) monitoring was done, fluctuations in the PSP were observed which varied from ranges -1.367 volts to -0.969 volts (DC) w.r.t standard Cu/Cu SO₃. In order to achieve the detailed data, critical points are found out and continuous recording data loggers were employed at those particular points. As a result, the percentage of time that the applied potential goes below the set threshold voltage in CP Analyzer has been arrived. The pipeline is in safe support level of -0.98 volts and thus optimum level of cathodic protection for ghatkesar pipeline has been arrived.

During the measurement by various instruments it has been noted that the potential fluctuations are high at CH: 566.300 since it has been passing under High Voltage AC transmission. From this report it is suggested that to offset the effects of the alternating current on that particular line pipe, an increase in cathodic protection current will be required to maintain the same protection level. Consequently, the life of sacrificial anode beds will be reduced and the current output of impressed current systems is increased. Hence further study for mitigation of the AC current which is causing fluctuations should be initiated

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