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RESEARCH ARTICLE

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Cathodic Protection Performance Assessment for Crude Oil Transportation Pipeline from Sarir Oilfield to Tobruk Refinery

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Abstract : Corrosion processes of metallic structures buried in soils or in contact with soils has long been a serious engineering and economic problem, as well as many other structures are buried in the soil, suffering from soil corrosion problems which affect mainly the external surfaces of these structures. This paper highlights and pay attention to preserve and protect petroleum equipment particularly pipeline from damage caused by corrosion throughout a case study which carried out in Tobruk Sarir transportation line which feeding Tobruk Refinery. This pipeline is exposed to extensive damage due to the underground corrosion processes unless suitable protection technique is used. The data of cathodic protection has been collected for pipeline from field study, to optimize the cathodic protection system. This study tries to assessment the performance of the cathodic protection system for the transportation pipeline with a length of 513 km. The period of the study extended from 2010 until 2023, whereas the results the few first years where compared with the recent years at the end of the period from 2019 to 2023. The field study was revealed that the cathodic protection system had been subjected to many attacks due to the decreasing in the protection effort, which was recorded in 2019 and 2023. The obtain data of protection voltage readings of study points revealed that less than 400 volts, which is much less than the required protection voltage. This leads to severe suffering of corrosion processes of transportation crude oil line.
Keywords*:* Transportation line, crude oil, corrosion, cathodic protection, assessment.

1. Introduction

Corrosion is the enemy of many industries in the world especially for the oil and gas industry, due to corrosion can reduce the thickness of the wall is made out of metal, It will be very dangerous if the metals become bumpy and a leak can potentially cause an explosion (Zaki, 2006).

Corrosion is known commonly as rust, an undesirable phenomenon which destroys the luster and beauty of objects and shortens their life. Damage from corrosion often leads to failures in refinery equipment, which interrupt refinery operations and create safety hazards. The existence as well as the degree of damage is dependent on the particular process operating conditions and contaminants present in the process stream. Everyone in the refining industry today, including the refinery owner, refinery operator, chemical engineer, mechanical engineer and process engineer are looking for ways to prevent or minimize the effects of corrosion. Billions of dollars are spent annually on corrosion related problems that could have been eliminated or reduced by applying corrosion fundamentals (Ahamed, 2003).

2. Mechanism of corrosion

For corrosion to take place, the formation of a corrosion cell is essential. A corrosion cell is essentially consisted of the following three components:

- Anode,
- Cathode**,**
- Electrolyte.

Anode: One of the two dissimilar metal electrodes in an electrolytic cell, represented as the negative terminal of the cell. Oxidation takes place at anode causing the electrons to be released and the anode is considered to be the more active metal.

Cathode: One of the two electrodes in an electrolytic cell represented as a positive terminal of a cell. Reduction takes place at the cathode and electrons are consumed.

Electrolyte: It is the electrically conductive solution (e.g., salt solution) that must be present for corrosion to occur (Shrier, 1993).

Consider a sample of zinc and a sample of copper immersed in a solution of zinc sulfate and copper sulfate solution, respectively, as shown in figure 1.2. Zinc (Anode) reaction 1.1 and the copper is the (cathode) reaction 1.2. In the reaction, electrons can be transferred from the corroding zinc to the copper through an electrically conducting path as a useful electric current. Zinc more readily loses electrons than copper, so placing zinc and copper metal in solutions of their salts can cause electrons to flow through an external wire which leads from the zinc to the copper. The two electrodes may also be connected through an external load of resistance; Re. Electrons begin to flow according to the following reactions:

$$\text{Zinc anode: } Zn \rightarrow Zn^{2+} + 2e^- \quad (1)$$

$$\text{Copper cathode: } Cu^{2+} + 2e^- \rightarrow Cu \quad (2)$$

The potential difference across cells, such as the Cu–Zn cell, has been analyzed, and it has been found to decrease with the cell current. The cell current increases with lower values of resistance, R_e. The increase in cell current with decreasing potential occurs as shown in figure 1 (Shrier, 1993).

3. Methods to control corrosion

Techniques for corrosion prevention can be categorized into five basic groups:

1 – The design

2 – Material selection

3 – The coating

4 – Cathodic protection

5- Use the inhibitors

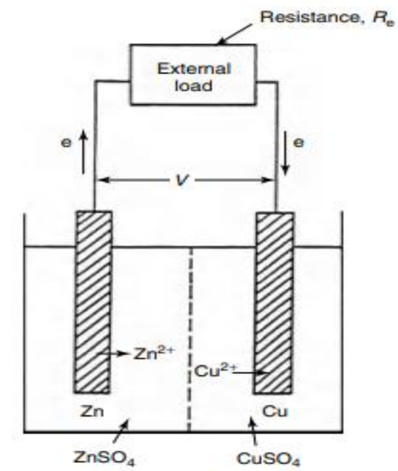

Figure 1. : Electrochemical cell

3.1 Methods of cathodic protection for corrosion control

Cathodic protection is a widely accepted method of corrosion control. Corrosion of above ground steel storage tank bottoms may be reduced or eliminated with proper application of cathodic protection. Cathodic protection is a technique for preventing corrosion by making the entire surface of the metal to be protected act as the cathode of an electrochemical cell. There are two systems of cathodic protection (Shrier, 1993).

3.1.1 Galvanic systems

Galvanic systems use a metal more active than the structure to be protected to supply the current required to stop corrosion (see Table 1 for a partial galvanic series). The more active metal is called an anode, commonly referred to as a galvanic anode or a sacrificial anode. The anode is electrically connected to the structure to be protected and buried in the soil. A galvanic corrosion cell develops and the active metal anode corrodes (is sacrificed) while the metal structure (cathode) is protected. As the protective current enters the structure, it prevents the flow of corrosion current from the metal surface. Current then returns to the galvanic anode through a metallic conductor (see Figure. 2.). Metals commonly used as galvanic anodes in soil are magnesium and zinc in either cast or ribbon form. The anodes are usually distributed around the perimeter of the tank or buried beneath the tank bottom. Galvanic systems are normally applied (William and Wei, 2007).

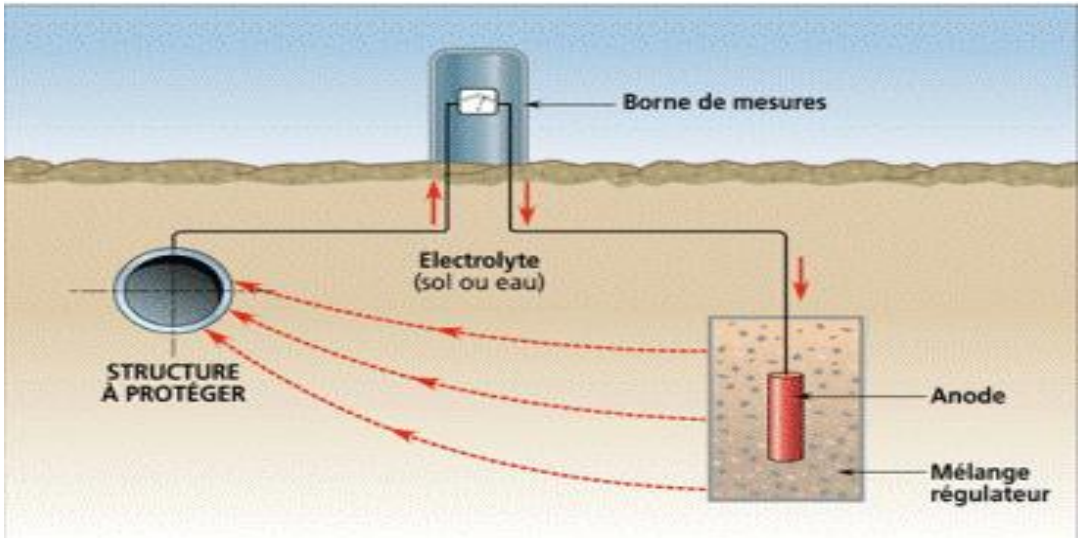

Figure 2. Galvanic Cathodic Protection with Sacrificial Anodes

3.1.2 Impressed current system

The second method of applying cathodic protection to an aboveground storage tank bottom is to use impressed current from an external source. Impressed current systems use direct current usually provided by a rectifier attached to an AC power source. The rectifier converts alternating current to direct current. Direct current from the rectifier flows to the buried impressed current anode, from the anode through the soil electrolyte, and onto the tank bottom as shown in Fig. 3.

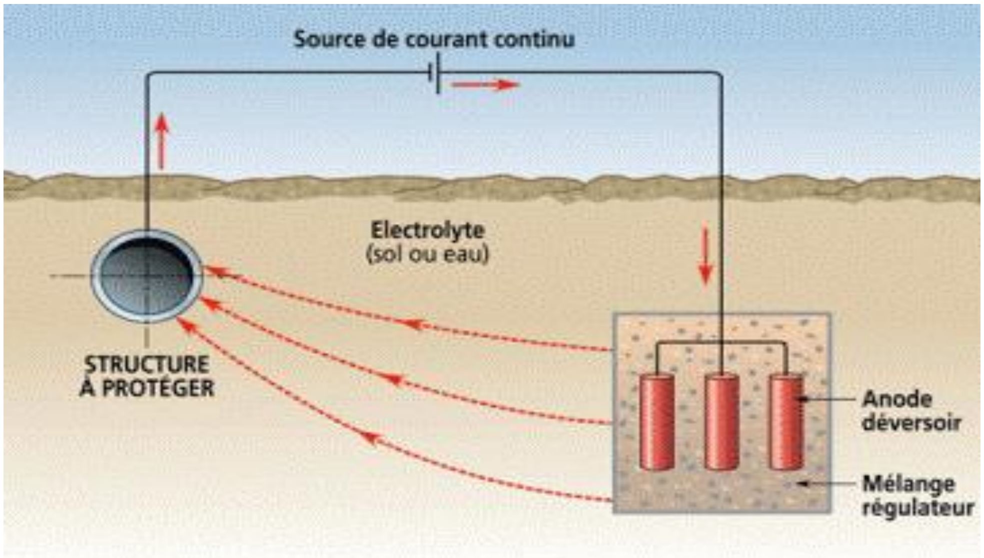

Figure 3 : Impressed Current Cathodic Protection

4. Types of corrosion

1. Atmospheric Corrosion, Erosion, temperature, moisture, rainfall & air pollutants (SO_2 , CO, CO_2 , H_2S).

2. Chemical Corrosion: Pure Acidic Corrosion Direct exposure to chemicals such as acids (H^+) and alkalis (OH^-).

3. Electrochemical Corrosion: Galvanic, Pitting & localized (Shrier, 1993).

5. The intrinsic and extrinsic modes of corrosion which occur in pipelines are:

(general corrosion, pitting, interganular corrosion, stress corrosion, crevice corrosion, galvanic corrosion, fretting corrosion, corrosion fatigue) (called electrochemical corrosion).

6. Location of study

The study was conducted on the Tobruk Sarir pipeline, as shown in figure 4. The length of Tobruk Sarir pipeline about 513 Km which supplies the Tobruk refinery with crude oil.

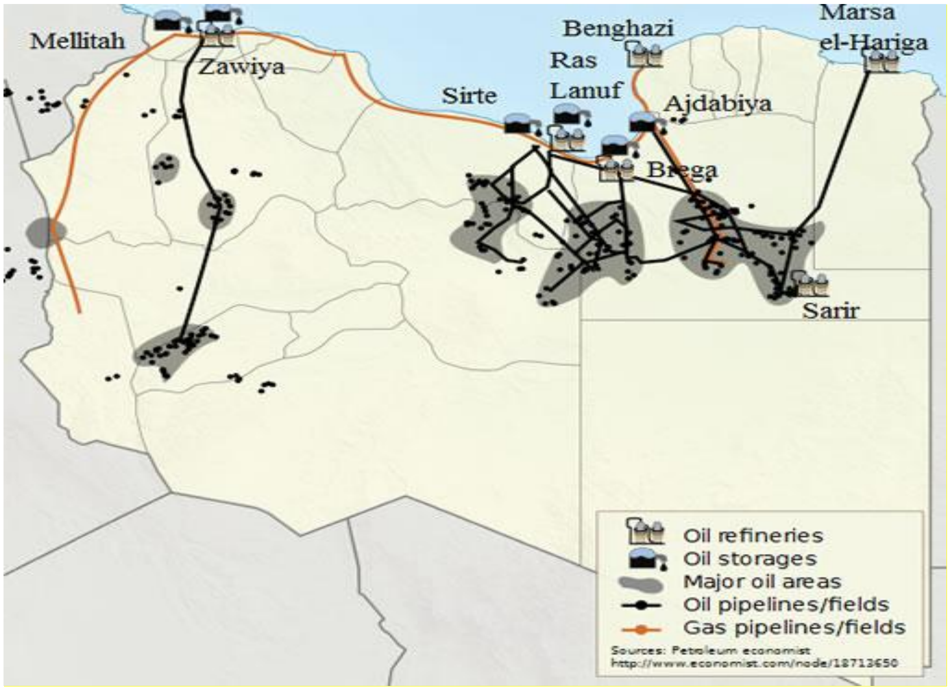

Fig .4 Image showing Sarir Tobruk pipeline.

5. Study importance

The importance of this study is to spotlight on the causes of corrosion and how to avoid it to reduce the economic losses which reduce the costs.

6. Problem statement

The statement of problem is represented by the serious corrosion effect of petroleum equipment e. g. transport pipelines, storage tanks etc. due to the corrosion process and their negative effects.

7. Study objective

The main objective of this study is the protection of the Tobruk Sarir pipeline against corrosion by applying cathodic protection technique which is regard as one of most methods to avoid corrosion.

8.The methodology

The methodology of this study has been take place throughout the following parameters:

8.1.The pipeline characteristics:

The pipeline specific characteristics are as follows:

1. Pipeline diameter: 34″.
2. Pipeline length: 513 km.

3. Pipeline length protected: 44 km.
4. Design pressure: 40 bar.
5. Normal operating pressure: 32.7 bar.
6. Material properties: Carbon steel XL45.
7. Wall thickness: 9.5 mm.
8. Burial depth: 0.75: 1.5 m.
9. Minimum normal temp: -10 C° (blow down).
10. Maximum normal temp: 24 C° (at pump outlet) (Md.Abdus and Quazi, 2007).

8.2. Cathodic protection system:

The pipeline is catholically protected by an impressed current system. The pipe-to soil potential is also monitored by the test posts are located at a nominal 4 km spacing along the pipeline route. The impressed current system was designed to cope with a 75% reduction in coating performance from an initial 20,000 ohm/m² to 5,000 ohm/m². In addition, there is a 100% over capacity in the cathodic protection station sizing.

The following criterion was set for the operation of the system. "Off" pipe to soil potentials or "Off" coupon potentials should be maintained more negative than -0.85V with respect to a Cu/ $CuSO_4$ reference electrode. "On" pipe to- soil potentials should not be more negative than -1.5 to reduce the risk of cathodic disbandment of the coating. The design for the C.P. system is based on coating deterioration (after 15/20 years). Calculations are based on following formulas (Corrosion Protection, 1997).

$$RL = \frac{\sigma}{\pi\, D\, T\, H} = Ohms/Km$$

$$RI = \frac{R}{n\, D\, 1000} = Ohms/Km$$

$$Rc = \sqrt{RL\, .\, RI} = Ohms$$

$$\alpha = \sqrt{\frac{RL}{RI}} = 1/Km$$

$$\alpha L = \sigma . L$$

$$Re = \frac{Rc}{t\,g\,h\,\alpha L} = Ohms$$

$$VM \;=\; Vm\,cosh\,\alpha = volts$$

$$I = VM\,/\,Re \;= Amps$$

Where:

R	=	Insulation resistance
Th	=	Pipe thickness.
D	=	Pipe diameter.
L	=	Pipe length to be protected
RL	=	Longitudinal resistance
RI	=	Transversal resistance
Rc	=	Characteristic resistance
σ	=	1/km Characteristic index
Re	=	Equivalent resistance
VM	=	Voltage between pipe and soil at each end
Vm	=	Voltage between pipe and soil at midpoint
I	=	protective current at each end of the pipe

8.3. Calculating of the cathodic protection station

Calculating the CP station (at station 500 km) using 5,000 ohms.m^2, the maximum protected distance is 44 km (overall 513 km) and the relevant maximum current required is 100 Amps (Md.Abdus and Quazi, 2007).

8.3.1. Calculation the longitudinal resistance

From the given data and using the following equation:

$$RL = \frac{\sigma}{\pi\,D\,T\,H} = Ohms/Km$$

The longitudinal resistance is RL = 5.9880 ohms km^{-1}

8.3.2. Calculation the transversal resistance

From the given data and using the following equation:

$$RI = \frac{R}{n\,D\,1000} = Ohms/Km$$

The Transversal resistance is RI = 0.2316 ohms km^{-1}.

8.3.3. Calculation the characteristic resistance

From the given data and using the following equation:

$$RI = \frac{R}{n\,D\,1000} = Ohms/Km$$

The Characteristic resistance is Rc = 1.177 ohms.

Figure 5 depicts the method of ON potential measurement.

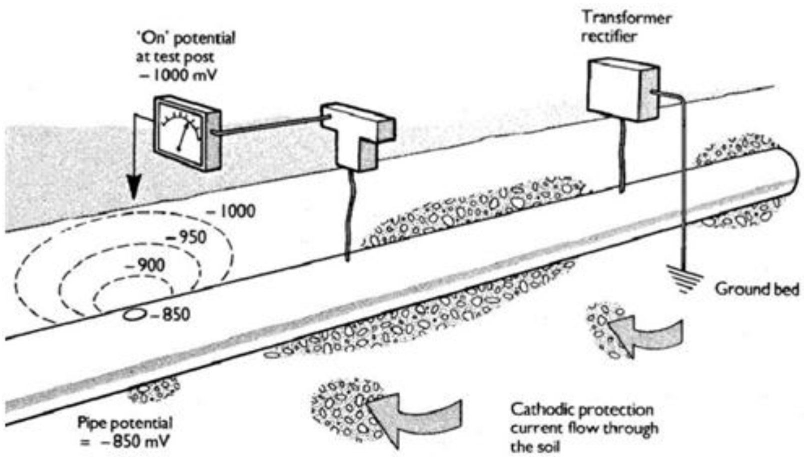

Figure 5: Measurement of ON Potential

8.4. Coating

The pipe is coated with wrapping. The coating was applied generally in accordance with Shell Expro Standard ES/014. The coating was applied by electrostatic spraying, white metal, blast cleaned surface. The surface of the pipe was pre-treated with a chromatic conversion coating to improve its resistance to cathodic disbonding. The dry film thickness was 350 ± 50 microns (Manak and Bahadur, 2005).

8.5. Transformer Rectifiers

- The transformer data as shown in figure 6.
- Cable route marker, 1700mm long
- Angle iron 50x50x5mm galvanized with 2 plates

- Transformer rectifier unit 60V/100A, oil cooled
- Transformer rectifier unit, oil cooled, with sunshade
- AC input : 415V, 3phase, 50Hz
- DC output: 60V/100A
- Output control : continuous 0 – 100A by auto transformer
- Hazardous area: None
- With top control cabinet,
- Oil tank, oil level, Thermometer, Silicagel Breather c/w over voltage protection
- Devices on AC and DC circuits, DC voltmeter 0-60V, DC Ammeter 0-100A

Figure 6: Transformer rectifier at Tobruk station

8.5.1. Anode junction box (AJB)

The Anode junction box consist of

1. Cast aluminum alloy box with dimensions 404 mm x 313 mm x 180 mm, complete with mounting plate,5 nos. shunts 50mV/10A,
2. Copper rail
3. Steel support(440 x 1250mm)
4. Galvanized steel conduct type M50

8.5.2. Magnetite Anodes chain type 25-5-5/105V

Magnetite anode string assembly with 25 nos. anodes, consisting 5chains with 5 nos magnetite anodes each. space between anodes 1.68m. Free length of 10mm^2 PVDF cable above top anode 105m , all plastic components of chain made from PVDF material , each chain provided with titanium suspension ring for fixing at supporting axle inside wellhead structure. This special type of magnetite anode chains are used for deep well anode ground beds, both open hole and close hole. As open hole anode ground bed they can be used in conjunction with non-conductive slotted casing without backfill but can also be used in close hole ground beds with coke backfill material in case of unstable or non-existing static water level.

All parts of anodes, anode chains and suspension devices are made of material resistant against low pH value, high chloride content of water and high concentration of chlorine gas. Each anode is center connected to the cable using copper compression clamp and a bronze connection spring. The internal space is filled with a two component mixture of polyurethane and polyester. Each anode chain has one individual lead cable connection ready for fixing on suspension device inside ground bed head structure (Basham et al., 2003).

8.6. Anode specification:

Table 1: Anode Specification

Diameter	60mm
Total length	740mm
Effective length	600mm
Total weight	6.2 kg
Min. effective mass	4.7 kg
Surface area	11.3dm^2
Max. current load (grounded)	4 A

8.7. Anode consumption and anode connection

1. The calculated consumption rate was 0.2 Kg/Ampere-year
2. Free length of 10mm^2 above PVDF cable above top anode 105m all plastic components
3. Magnetite anode string assembly with 25nos consisting of 5 chains made from PVDF.

8.9. Test points

The (3 inch) pipe which moves the ground base, containing copper cable to take readings of voltage. Figure 8 shows one of test-point that used in CP system

Figure 8: Test point

8.10. Soil resistivity measurements

Soil resistivity measured by soil resistance, BBC GOERZ METAWATT Fig.(9). The 4 pins should be driven into the ground in the straight line at 50 cm spacing. Good contact with the soil is important. The two "C" binding posts are connected to the end pins, and the two P" binding posts are connected to the adjust center pins (Md.Abdus and Quazi, 2007).

Figure 9: Soil resistivity meter

8.11. Copper / Copper sulfate electrode

The figure 10: shows Cu / $CuSO_4$ electrode consists of a piece of copper, a saturated solution of copper sulfate in contact with a copper; a porous member placed in contact with a soil. Excess crystals are added, to ensure that the solution always will be saturated (Pierre, 2007).

Figure 10 : Copper / Copper sulfate electrode

9. Results and Discussion

Throughout this study a comparison of assessment performance of pipeline system in the period between 2010 to 2018 before the system is exposed to infringement and sabotage in 2019.The AGOCO pipeline is fully protected multi cathodic protection stations , the feeder consists of one- phase bridge rectifier fed through the one - phase transformer with the rated voltage ,all transformer rectifiers were adjusted at value of voltage 60Volt.

9.1. Adjustment of the transform rectifiers and anodes connection

- Cleaning of transformers from dirt, dust and change the oil cooling
- Adjust anodes cable for series anodes
- Install 61 test posts route of line
- Adjusted parameters for the amount of current transformers to be given the amount of current for protection

9.2. Potential measurements

Table (3) shows the soil potential measurements readings in 2010, when the pipeline was fully protection along the line to the booster station and readings potential measurements in 2019, 2023 when the pipeline became partially protected, the output of transformer rectifiers used obtained in table (2). The figure (11) shown the relation between distance (km) and the potential (volts) at year of (2010) as it was clear that the pipeline was fully protected , while the figures (12), (13) show the relationship between distance (km) and the potential (volts) at years of (2019) and (2023) Where the pipeline was not fully protected, while The figure (14) shows the comparison between distance (km) and the potential (volts) at year of (2010, 2019 & 2023).

To make a pipeline to soil test observation, the lead wire attached to copper sulphate electrode is attached to positive (+) post of the meter. A wire attached to the negative (-) post of the meter is attached solidly to the pipe at any convenient point. This contact can be made by clipping directly to an above – ground valve or test point .the dotted line shows typical pipe-to-soil measurements on all test points.

Table (2) Transformer rectifiers reading of AGOCO CP systems

LOCATION	Point 500km
C.P.SYSTEM	
TR OUTPUTS	100A , 45V

Table (3) shown the relation between distance (km) and the potential (volts) at years of (2010, 2019 & 2023) and soil resistivity at 2023.

Distance Km	soil resistivity Ω*m	Volts 2010	Volts 2019	Volts 2023
448	12220	1562	675	1200
452	12080	1537	715	1170
456	11960	1474	750	1120
460	12050	1370	780	1085
464	11980	1433	825	1062
468	11960	1384	855	1030
472	11860	1511	900	1003
476	11777	1479	950	985
480	11714	1567	980	970
484	11720	1523	990	920
488	11690	1414	1020	870
492	11665	1520	1032	853
496	11690	842	1105	842
500	11610	813	1102	813
504	11577	796	1130	796
508	11553	782	1180	782
512	11480	765	1210	765

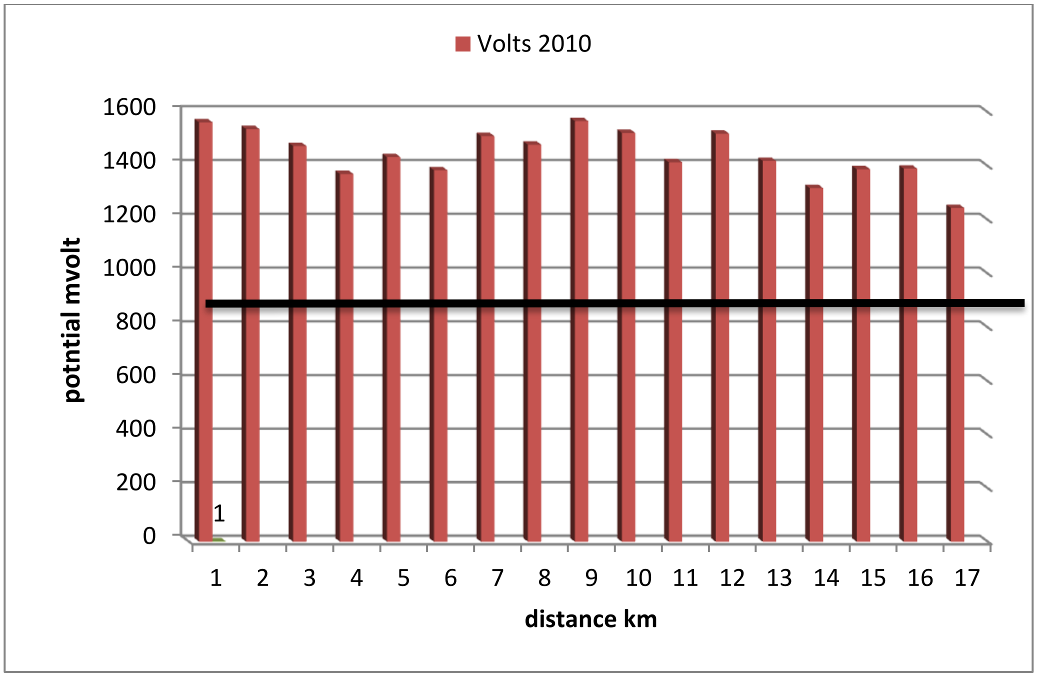

Figure 11. Shown the relation between distance (km) and the potential (volts) at year of (2010)

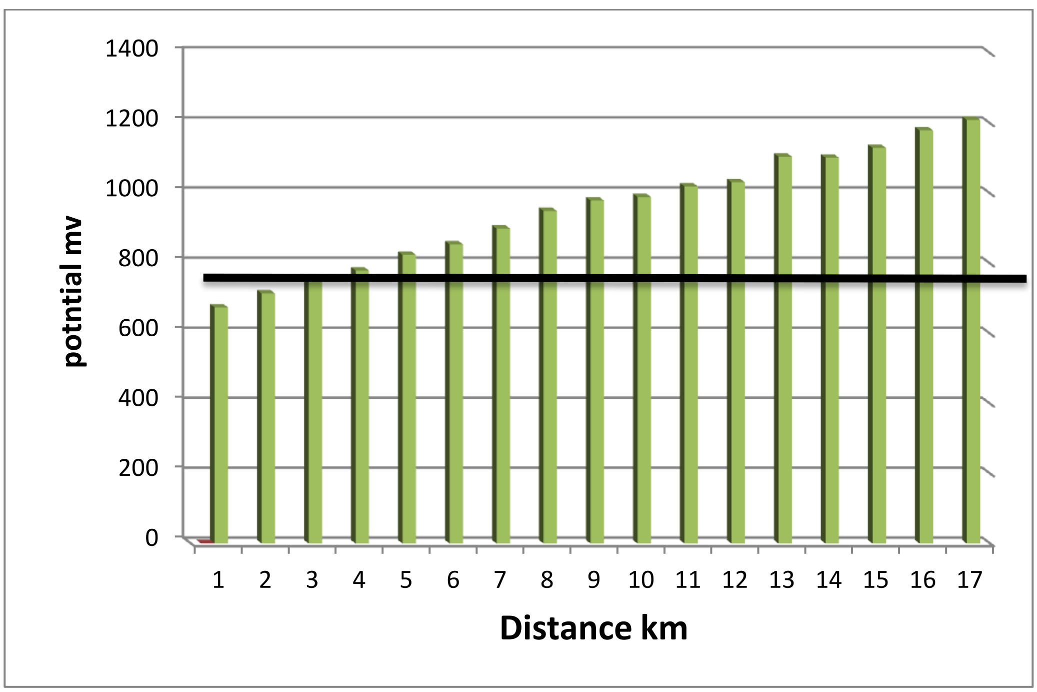

Figure 12. Shown the relation between distance (km) and the potential (volts) at year of (2019)

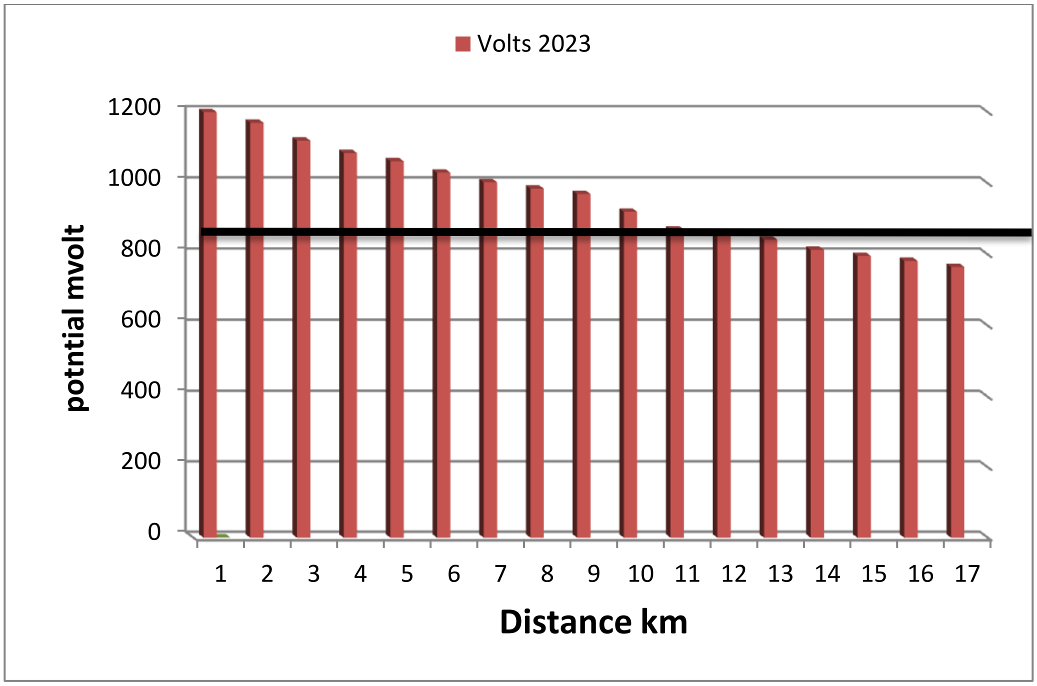

Figure 13. shown the relation between distance (km) and the potential (volts) at year of (2023)

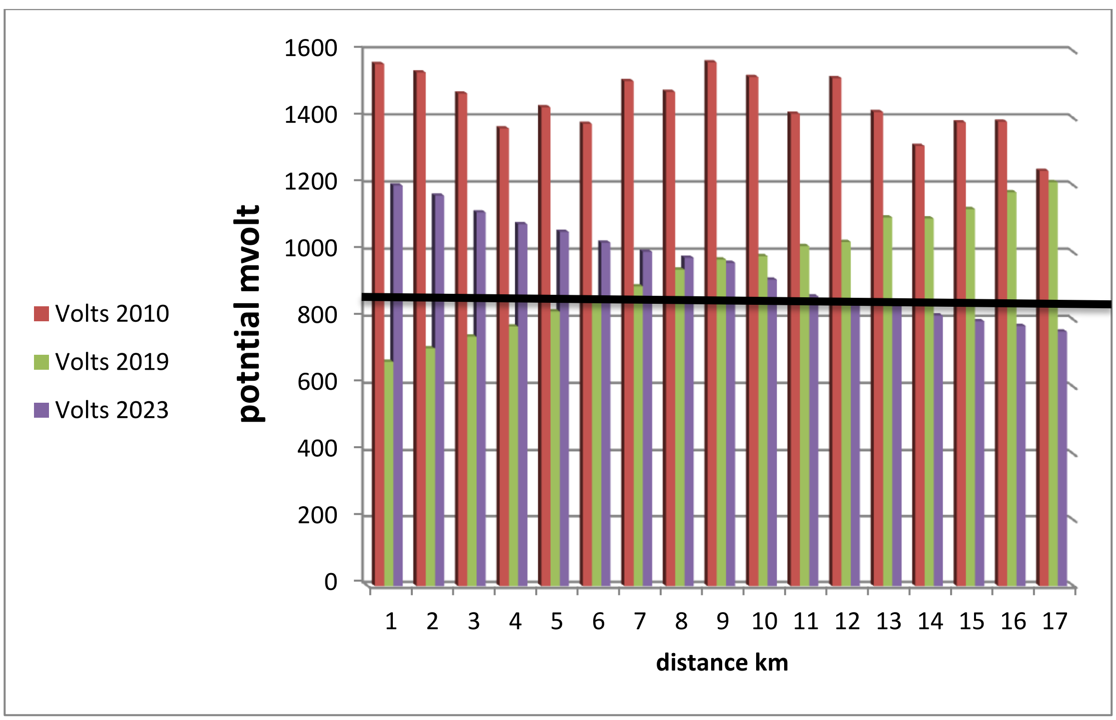

Figure 14. shown the relation comparing between distance (km) and the potential (volts) at year of (2010, 2019 & 2023)

9.3. Soil resistivity measurements

Soil resistivity is the resistance measured between two opposing surfaces of $1m^3$ of homogeneous soil material, usually measured in ohm-m or ohm-cm. soil resistivity has a direct effect on the resistance the grounding system. The evaluation of the resistivity of the local soil can determine the best location , depth, and size of electrodes in the ground system ,

The resistivity range can go from 1 ohm-cm to the upwards of over 1,000,000ohm-cm. Moisture content can be a large factor in determining the resistivity of the local soil. The drier soil has higher resistivity.

Measuring the resistivity of the local soil can be done with specific metering device. The process is sometimes referred to as the four terminal poles. Figure (9) shows basic circuit to measure soil resistivity, including a large sample of soil. For practical circumstances, distance (b) depth of electrode, must be small compared to (a) and the formula as $\rho = 2\pi a R$

where:

ρ = resistivity (ohm-m)

a = distance between probes (m)

R = the resistance determining by the testing device

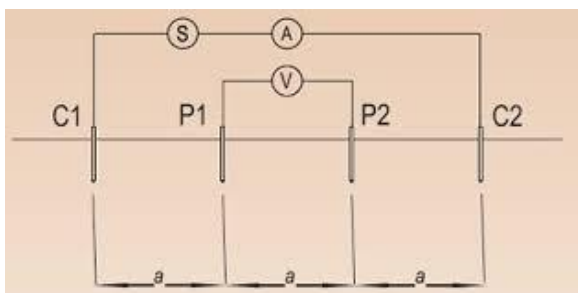

Figure (15) four – terminal measurement of soil resistivity

Table (4) corrosively ratings based on soil resistivity

Soil resistivity (ohm-m)	Corrosive ratting
>20000	Essentially – non corrosive
10000 to 20000	Mildly corrosive
5000 to 10000	Moderately corrosive
3000 to 5000	corrosive
1000 to 3000	Highly corrosive
<1000	Extremely corrosive

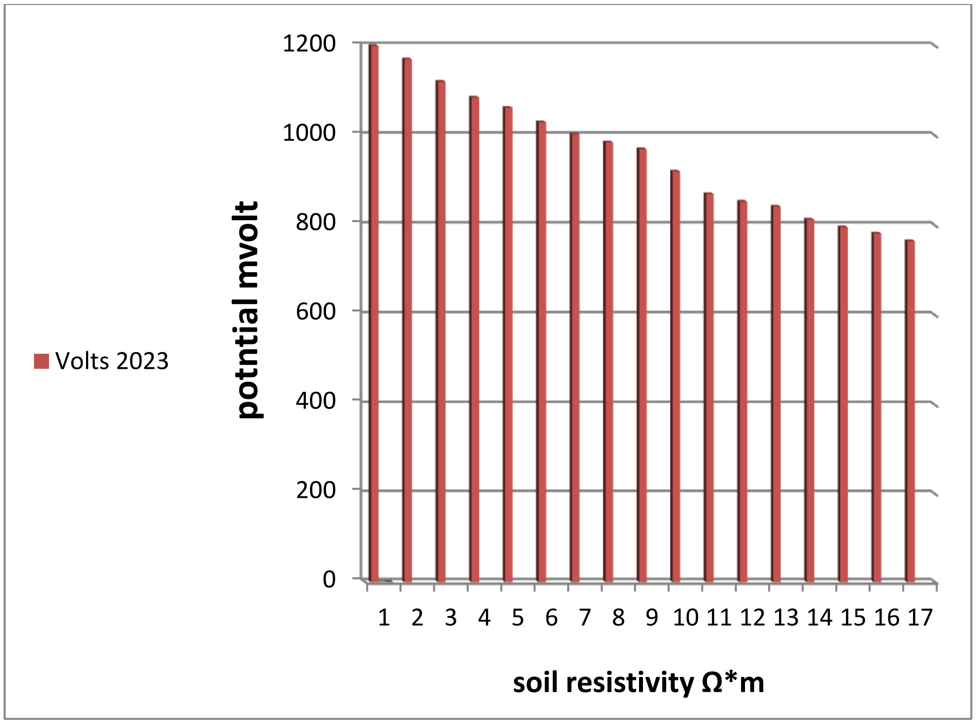

Figure 16. Shown the relation between the potential (volts) and soil resistivity Ω*m at year of (2023).

10. Conclusion

In light of the previous results of transportation line for Sarir-Tobruk refinery to assessment the cathodic protection performance which carried out throughout the comparing between data of voltage in 2010, 2019 and 2023, the following conclusions can be drawn:

1- The cathodic protection system of the transportation line for Arabian Gulf Oil Company has a good performance since 2010 until 2019.
2- Since the protection system was attacked and vandalized in 2019, it has become completely inoperable.
3- Only a distance of 44 km is protected by the cathodic protection system from the total length of the pipeline.
4- The rest of the line, which is 213 km long, is not protected and is subject to corrosion at any moment.
5- Several leaks occurred in a line due to the lack of protection

11. Recommendations

1- The effectiveness of c.p. program depends on periodic maintenance of installed system as well as on the analysis of recorded potential data, all information should be kept in records with data such as :

- Monthly the rectifier chick.
- Periodic maintenance of rectifiers
- Periodic maintenance of solar panels
- Periodic maintenance of the deep anodes
- Inspection of pipeline coating
- Reports of any failure cases

2- Quickly start installing solar panels that provide the system with the required electric current.
3- Provide protection for solar panels so that they are not damaged again.
4- Repair the transformer rectifier (at point 500km).

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