CHAPTER ONE

INTRODUCTION

1.1 Background

Corrosion is the result of an electrochemical reaction driven by a potential difference between two electrodes, an anode and a cathode, connected by an electronic path and immersed in the same electrolyte see Figure 1.1, in the case of uniform corrosion, a multitude of microscopic anodic and cathodic sites exist on the surface of the metal structure.[1]

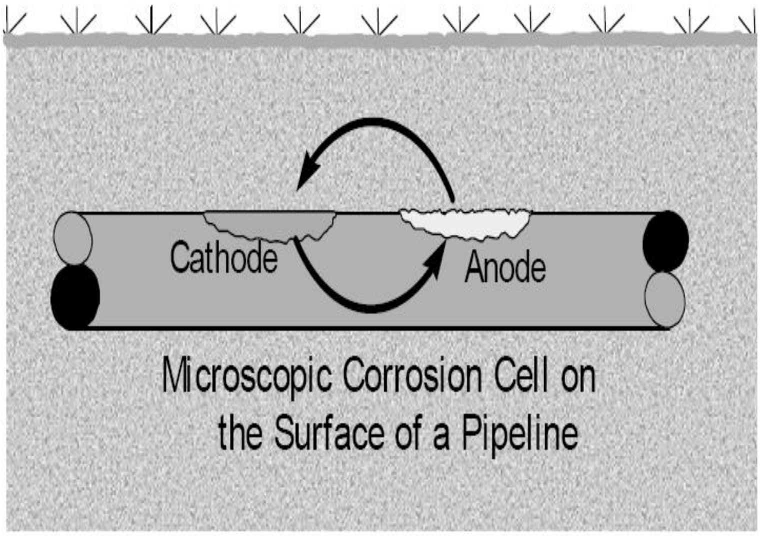

Figure 1.1: Microscopic corrosion cell

The concept of Cathodic Protection (CP) involves reducing the potential difference between the local anodic and cathodic sites to zero, resulting in zero corrosion current flow; this can be accomplished by impressing current onto the structure from an external electrode and polarizing the cathodic sites in an electronegative direction. As the potentials of the cathodic sites polarize toward the potentials of the anodic sites, corrosion current is reduced, when the potentials of all cathodic sites reach the open circuit potential of the most active anodic sites, corrosion is eliminated on the structure, The structure is now the cathode of an intentional macroscopic corrosion cell.[2]

1.2 Problem statement:

The corrosion in pipe line and how to face it, also improve the protection efficiency.

1.3 Objectives:

- Studying the main corrosion that accrued in pipelines
- Design impressed current cathodic protection system.
- Remote monitoring and control the stations of impressed current cathodic.

1.4 Methodology:

Two microcontrollers is used, one in the sending unit (stations outside) and the other in the receiving unit (inside office), the radio frequency transceiver used to send and receive data to and from each controller wirelessly.

The microcontrollers used to coordinate the functions of various hardware circuitries; Service request circuit or keypad and a Potentiometer are used as input, a variable voltage regulator and Liquid crystal display are used as output.

1.5 Research layout:

This research contains five chapters:

The first chapter gives background, problem statement, objectives and the methodology.

The second chapter comprises an introduction, description of corrosion process, form of corrosion, methods of protection from corrosion.

The third chapter includes an introduction, cathodic protection principles, application, methods and design including the impressed current cathodic protection system design.

The fourth chapter contains a brief definition for the components which used in this research and the system operation of the impressed current cathodic protection system parameters.

The fifth chapter encompasses the conclusion and recommendations of the project.

CHAPTER TWO
THE CORROSION

2.1 Introduction

The term corrosion is used to describe the reaction of a material with its surroundings that produces measurable changes and can lead to damage. With metallic materials and aqueous solutions, the reactions are in general of an electrochemical nature. However, in addition, pure chemical reactions or entirely physical processes can also be occurring. Not every process necessarily leads to damage. This is a question of the extent of the reaction and the demands on the function of material or medium, which should always be considered together. Damage is said to occur when this function is impaired. Corrosion protection is designed to prevent such detrimental action. [1]

2.2 Description of corrosion:

Metals are elements that tend to lose electrons when they are involved in chemical reactions, and nonmetals are those elements that tend to gain electrons, sometimes these elements form ions, charged elements or groups of elements, metallic ions, because they are formed from atoms that have lost electrons, are positively charged (the nucleus is unchanged). When an atom or ion loses electrons it is said to have been oxidized. A common oxidation reaction in corrosion is the oxidation of neutral iron atoms to positively charged iron ions:

$$Fe \text{ » } Fe^{+2} + 2e^{-} \qquad (2.1)$$

Where:

Fe : iron

Fe^{+2} :iron cation

e^-:electron

The electrons lost from a metal must go somewhere, and they usually end up on a nonmetallic atom forming a negatively charged nonmetallic ion. Because the charge of these ions has become smaller (more negative charges) the ion or atom which has gained the electron(s) is said to have been reduced.

$$4H^+ + O_2 + 4e^- \text{ » } 2H_2O \qquad (2.2)$$

Or

$$2H^+ + 2e^- \text{ » } H_2 \qquad (2.3)$$

Where:

O_2 : oxygen

H_2O : water molecule

H_2 : hydrogen

While other reduction reactions are possible, the reduction of oxygen is involved in well over 90% of all corrosion reactions. Thus the amount of oxygen presents in an environment, and its ability to absorb electrons, is an important factor in determining the amount of oxidation, or corrosion, of metal that occur, the two metal strips shown in Figure 2.1 are exposed to the same acid.

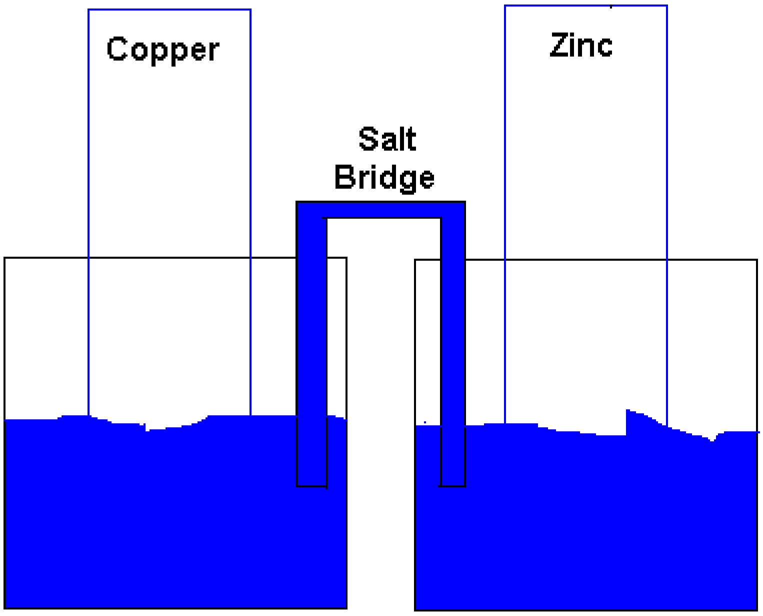

Figure 2.1: electrochemical cell

Both metals undergo similar oxidation reactions:

$$Cu \gg Cu^{+2} + 2e^{-} \qquad (2.4)$$

and

$$Zn \gg Zn^{+2} + 2e^{-} \qquad (2.5)$$

Where:

Cu : copper

Zn : zinc

Cu^{+2}: copper cation

Zn^{+2} : zinc cation

The electrons freed by the oxidation reactions are consumed by reduction reactions.

On the copper the reduction reaction is:

$$4H^{+} + O_2 + 4e^{-} \gg 2H_2O \qquad (2.6)$$

The corrosion rate of the copper is limited by the amount of dissolved oxygen in acid, on the zinc the reduction reaction is:

$$2H^{+} + 2e^{-} \text{ » } H_2 \tag{2.7}$$

The hydrogen ions are converted to hydrogen gas molecules and can actually be seen bubbling off from the acid, if we now connect the two metal samples with a wire and measure the electricity through the connecting wire, we find that one of the electrodes becomes different in potential than the other and that the corrosion rate of the copper decreases while the corrosion rate of the zinc increases, by connecting the two metals, we have made the copper a cathode in an electrochemical cell, and the zinc has become an anode, the accelerated corrosion of the zinc may be so much that all of the oxidation of the copper stops and it becomes protected from corrosion.[1]

2.3 Form of corrosion

Uniform corrosion**:** This is also called general corrosion. The surface effect produced by most direct chemical attacks (e.g., as by an acid) is a uniform etching of the metal, on a polished surface, this type of corrosion is first seen as a general dulling of the surface and, if allowed to continue, the surface becomes rough and possibly frosted in appearance. The discoloration or general dulling of metal created by its exposure to elevated temperatures is not to be considered as uniform etch corrosion. The use of chemical-resistant protective coatings or more resistant materials will control these problems, while this is the most common form of corrosion, it is generally of little engineering significance, because structures will normally become unsightly and attract maintenance long before they become structurally affected.

Galvanic corrosion: Galvanic corrosion occurs when two dissimilar metals are in contact in a solution. The contact must be good enough to conduct electricity, and both metals must be exposed to the solution. The driving force for galvanic corrosion is the electric potential difference that develops between two metals. This difference increases as the distance between the metals in the galvanic series increases, when two metals from the series are in contact in solution, the corrosion rate of the more active (anodic) metal increases and the corrosion rate of the more noble (cathodic) metal decreases, three conditions must exist for galvanic corrosion to occur; electrochemically dissimilar metals must be present, the metals must be in electrical contact and must be exposed to an electrolyte.

Pitting corrosion: Pitting is a form of extremely localized attack that results in holes in the tube walls. It occurs when the corrosive environment penetrates the passivized film in only a few areas as opposed to the overall surface. As stated earlier, Pitting corrosion is therefore simple galvanic corrosion, occurring as the small active area is being attacked by the large passivated area. It is one of the most destructive forms of corrosion and also one of the most difficult to predict in laboratory tests... It is generally promoted by low-velocity or stagnant conditions and by the presence of chloride ions. Once a pit is formed, the solution inside it is isolated from the bulk environment and becomes increasingly corrosive with time, the high corrosion rate in the pit produces an excess of positively charged metal cations, which attract chloride anions. In addition, hydrolysis produces H+ ions, the increase in acidity and concentration within the pit promotes even higher corrosion rates, and the process becomes self-sustaining, similar to pitting is crevice corrosion; this corrosion occurs any time liquid flow is kept away from the attacked surface. It is common between single or twin ferrule fittings and tube clams surfaces, we find in many split seal applications. Salt water applications are the most severe problem because of the salt water low PH and its high chloride content. Due to the tight connections no oxygen is available to passivate the stainless steel, chloride pit the passivated stainless steel surface, the low PH salt water attacks the active layer that is exposed, the corrosion unhampered under the tight fitting clamp.

Chloride stress corrosion: Stress corrosion cracking is the brittle failure of a metal by cracking under tensile stress in a corrosive environment. Chloride is the main contributor to SCC of stainless steels. High chloride concentrations, resulting from high chloride levels in the makeup water and/or high cycles of concentration, will increase susceptibility, if the tube piece is under tensile stress, either because of operation or residual stress left during manufacture, the pits will deepen even more, Chloride stress cracking is a serious problem in industry and not often recognized by the people involved, this is the main reason that Hastelloy C is recommended for several severe industry applications.

Erosion corrosion: Also known as flow- assisted or flow- accelerated corrosion, this is an accelerated or increase in rate of deterioration or attack on a metal because of relative movement between a corrosive fluid and the metal surface, resulting from the combination of mechanical and chemical wear. The liquid velocities in some tubes prevent the protective oxide passive layer from forming on the metal surface. The suspended solids also remove some of the passivated layer increasing the galvanic action. You see this type of corrosion very frequently appears near the eye of a pump impeller. Erosion corrosion is characterized in appearance by grooves, waves, round holes and valleys which usually exhibit a directional pattern.

Fretting corrosion: Fretting corrosion occurs as a result of repeated wearing, weight and /or vibration on an uneven, rough surface. The corrosion results in pits and grooves with occur on the surface of the tube. As mentioned earlier, 300 series stainless steel passivates its self by forming a protective chrome oxide layer whenever it is exposed to free oxygen. This oxide layer is very hard and when it imbeds into a soft elastomer it will cut and damage the shaft or sleeve rubbing against it.

High-temperature corrosion: Fuels used in gas turbines, diesel engines and other machinery, which contain vanadium or sulfates can, during combustion, form compounds with a low melting point. These compounds are very corrosive towards metal alloys normally resistant to high temperatures and corrosion, including stainless steel. High temperature corrosion can also be caused by high temperature oxidization, sulfidation and carbonization.

Intergranular corrosion: All austenitic stainless steels (the 300 series, the types that "work hardens") contain a small amount of carbon in solution in the austenite. Carbon is precipitated out at the grain boundaries, of the steel, in the temperature range of 565°C (1050° F), to 870°C (1600° F). This is a typical temperature range during the welding of stainless steel, this carbon combines with the chrome in the stainless steel to form chromium carbide, starving the adjacent areas of the chrome they need for corrosion protection. In the presence of some strong corrosives an electrochemical action is initiated between the chrome rich and chrome poor areas with the areas low in chrome becoming attacked, the grain boundaries are then dissolved and become nonexistent, alloy the metal with strong carbide former. The best is columbium, but sometimes titanium is used. The carbon will now form columbium carbide rather than going after the chrome to form chrome carbide. The material is now said to be "stabilized". [1]

2.4 Protection from Corrosion

The protection from corrosion consists of:

2.4.1 Surface treatments

Applied coatings: Plating, painting, and the application of enamel are the most common anticorrosion treatments. They work by providing a barrier of corrosion-resistant material between the damaging environment and the structural material. Aside from cosmetic and manufacturing issues, there may be tradeoffs in mechanical flexibility versus resistance to abrasion and high temperature, plating usually fail only in small sections, but if the plating is more noble than the substrate (for example, chromium on steel), a galvanic couple will cause any exposed area to corrode much more rapidly than an unplated surface would. For this reason, it is often wise to plate with active metal such as zinc or cadmium, painting either by roller or brush is more desirable for tight spaces; spray would be better for larger coating areas such as steel decks and waterfront applications. Flexible polyurethane coatings, like Durabak-M26 for example, can provide an anti-corrosive seal with a highly durable slip resistant membrane. Painted coatings are relatively easy to apply and have fast drying times although temperature and humidity may cause dry times to vary. [2]

Reactive coatings**:** If the environment is controlled (especially in recirculating systems), corrosion inhibitors can often be added to it. These chemicals form an electrically insulating or chemically impermeable coating on exposed metal surfaces, to suppress electrochemical reactions. Such methods make the system less sensitive to scratches or defects in the coating, since extra inhibitors can be made available wherever metal becomes exposed, chemicals that inhibit corrosion include some of the salts in hard water (Roman water systems are famous for their mineral), chromates, phosphates, polyaniline, polymers and a wide range of specially-designed chemicals that resemble surfactants (i.e. long-chain organic molecules with ionic end groups). [2]

Anodization: Aluminum alloys often undergo a surface treatment. Electrochemical conditions in the bath are carefully adjusted so that uniform pores, several nanometers wide, appear in the metal's oxide film. These pores allow the oxide to grow much thicker than passivating conditions would allow. At the end of the treatment, the pores are allowed to seal, forming a harder-than-usual surface layer. If this coating is scratched, normal passivation processes take over to protect the damaged area. Anodizing is very resilient to weathering and corrosion, so it is commonly used for building facades and other areas where the surface will come into regular contact with the elements. While being resilient, it must be cleaned frequently. If left without cleaning, staining will naturally occur.

Biofilm coatings: A new form of protection has been developed by applying certain species of bacterial films to the surface of metals in highly corrosive environments. This process increases the corrosion resistance substantially. Alternatively, antimicrobial-producing biofilms can be used to inhibit mild steel corrosion from sulfate-reducing bacteria. [2]

2.4.2 Controlled permeability formwork

Controlled permeability formwork is a method of preventing the corrosion of reinforcement by naturally enhancing the durability of the cover during concrete placement. It has been used in environments to combat the effects of carbonation, chlorides, frost and abrasion. [2]

2.4.3 Rate of corrosion

A simple test for measuring corrosion is the weight loss method.[The method involves exposing a clean weighed piece of the metal or alloy to the corrosive environment for a specified time followed by cleaning to remove corrosion products and weighing the piece to determine the loss of weight. The rate of corrosion (R) is calculated as:

$$R = kW/(\rho At) \tag{2.9}$$

Where:

K: constant

W: the weight loss of the metal in time (kg).

A: the surface area of the metal exposed (m^2).

P: the density of the metal (in g/cm^3).[2]

2.4.4 Cathodic protection

Cathodic protection suppresses the corrosion current that causes damage in a corrosion cell and forces the current to flow to the metal structure to be protected. Thus, the corrosion or metal dissolution is prevented.

In practice, cathodic protection can be achieved by two application methods, which differ based on the source of the protective current, an impressed-current system uses a power source to force current from inert anodes to the structure to be protected. A sacrificial-anode system uses active metal anodes, for example, zinc or magnesium, which are connected to the structure to provide the cathodic-protection current.[2]

CHAPTER THREE

CATHODIC PROTECTION

3.1 Introduction

Cathodic Protection is a technique to control the corrosion of a metal surface by making it work as a cathode of an electrochemical cell. This is achieved by the polarization of all noble potential areas (cathodes) to the most active potential on the metal surface. Cathodic Protection is realized by making the structure a cathode of a direct current circuit, the first practical use of cathodic protection is generally credited to Sir Humphrey Davy in the 1820s. Davy's advice was sought by the Royal Navy in investigating the corrosion of copper sheeting used for cladding the hulls of naval vessels. Davy found that he could preserve copper in sea water by the attachment of small quantities of iron or zinc; the copper became, as Davy put it, "cathodically protected".

The most rapid development of cathodic-protection systems was made in the United States of America to meet the requirements of the rapidly expanding oil and natural gas industry which wanted to benefit from the advantages of using thin-walled steel pipes for underground transmission, for that purpose the method was well established in the United States in 1945 , in the United Kingdom, where low-pressure thicker-walled cast-iron pipes were extensively used, very little cathodic protection was applied until the early 1950s. The increasing use of cathodic protection has arisen from the success of the method used from 1952 onwards to protect about 1000 miles of wartime fuel-line network that had been laid between 1940 and 1944; the method is now well established.

Cathodic protection can, in principle, be applied to any metallic structure in contact with a bulk electrolyte. In practice its main use is to protect steel structures buried in soil or immersed in water. It cannot be used to prevent atmospheric corrosion.

Structures commonly protected are the exterior surfaces of pipelines, ships' hulls, jetties, foundation piling, and steel sheet-piling and offshore platforms. Cathodic protection is also used on the interior surfaces of water-storage tanks and water-circulating systems. However, since an external anode will seldom spread the protection for a distance of more than two or three pipe-diameters, the method is not suitable for the protection of small-bore pipework, cathodic protection has also been applied to steel embedded in concrete, to copper-based alloys in water systems, and, exceptionally, to lead-sheathed cables and to aluminum alloys, where cathodic potentials have to be very carefully controlled. [2]

3.2 Principle of cathodic protection

To live a long and productive existence, propane tanks and metallic piping also need protection, Cathodic Protection. In general terms, Cathodic Protection can be used to protect underground steel propane tanks and piping from corrosion. This is done by making the pipe a cathode.
Corrosion can be defined as a disease of steel. Coating the steel tank like many of the manufacturers do in the factory is the first line of defense against corrosion; cathodic protection is the second line of defense. It will make a steel propane tank and its piping immune to the disease of corrosion. [2]

3.3Application of cathodic protection:

i. Pipelines
ii. Ships and boats
iii. Marine
iv. Steel in concrete
v. Internal cathodic protection

vi. Automobiles

3.4 Methods of applying cathodic protection

Cathodic protection may be achieved in either of two ways, by the use of an impressed current from an electrical source, or by the use of sacrificial anodes (galvanic action).

3.4.1 Impressed current:-

The arrangement for protecting a buried pipeline is illustrated in Figure (3.1); the buried pipe receives current from a DC power source via an auxiliary inert electrode buried in the ground.

The pipe becomes the cathode and the auxiliary electrode the anode. The auxiliary electrode sometimes consists of scrap iron. In this case the iron will dissolve from the anode by reaction and the electrode is described as a consumable anode. If the anode is a noble metal or an electrochemically inert material, the surrounding environment will be oxidized and in water reaction will occur. In saline solutions, however, chlorine may be produced at the anode. This may present problems in confined spaces.

$$2H_2O > O_2 + 4H^+ + 4e \qquad (1.3)$$

- Advantages:

i. Can be designed for a wide range of voltage and current output.
ii. High ampere/year output available from single anode installation.
iii. Large area can be protected.
iv. Variable voltage and current output.
v. Applicable for high resistivity soil.

- Disadvantages:

i. The requirement for an outside power source.
ii. Higher maintenance requirements.

iii. A significantly higher monitoring and maintenance effort is required in comparison to sacrificial anode systems.

- Applications of Impressed Current Cathodic Protection:

Typical uses of impressed current are:

i. For large current requirements, particularly for bare or poorly coated structures.
ii. In all electrolyte resistivity.
iii. As an economical way of protecting structures having dissipated galvanic anodes
iv. To overcome stray current or cathodic interference problems

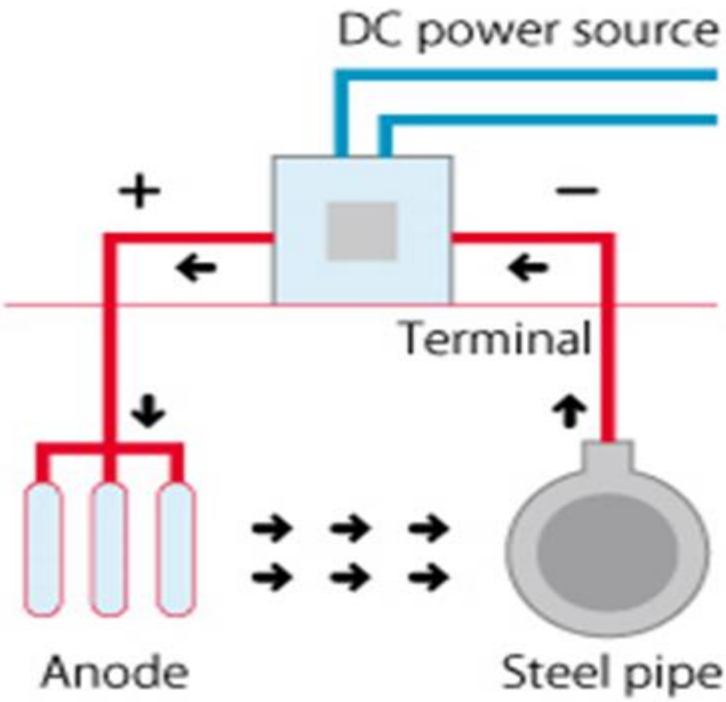

Figure 3.1: Impressed current system

3.4.2 Sacrificial anodes

Second type of cathodic protection system is the sacrificial anode. The anode is made from a metal alloy with a more "active" voltage (more negative electrochemical potential) than the metal of the structure it is protecting (the cathode), the difference in potential between the two metals means the sacrificial anode material corrodes in preference to the structure, this effectively stops the oxidation reactions on the metal of the structure being protection, there must be two other conditions existing besides the anode and the cathode for the sacrificial anode method to work. There must be a return current path for the electrons to flow from the anode to the material it is protecting (being in physical contact is the usual path) and an electrolyte (water, humidity) to convey the electrons.

Sacrificial anodes generally come in three metals: magnesium, aluminum, and zinc. Magnesium has the most negative electro potential of the three -see galvanic series- and is more suitable for on-shore pipelines where the electrolyte (soil or water) resistivity is higher. If the difference in electro potential is too great, the protected surface (cathode) may become brittle or cause disbanding of the coating, zinc and aluminum are generally used in salt water, where the resistivity is generally lower. Typical uses are for the hulls of ships and boats, offshore pipelines and production platforms, in salt-water-cooled marine engines, on small boat propellers and rudders, and for the internal surface of storage tanks. [2]

- Advantages:

i. Simple to install.
ii. Independent of any source of electric power.
iii. Suitable for localized protection.
iv. Less liable to cause interaction on neighboring structures.

- disadvantages :

i. Current capacity limited by anode mass and self-consumption at low current density.
ii. Lower driving voltage means the anodes may not work in high-resistivity environments.

iii. Often require that structure be electrically isolated from other structures and ground.

iv. Anodes are heavy and will increase water resistance on moving structures or pipe interiors.

v. Where D.C. power is available, electrical energy can be obtained more cheaply than by galvanic anodes.

vi. Where large arrays are used wiring is needed due to high current flow and need to keep resistance losses low.

- Applications of galvanic anode systems:

The following are among the conditions where galvanic anodes are used:

i. When a relatively small amount of current is required.

ii. Usually lower resistivity electrolytes.

iii. For local cathodic protection to provide current to a specific area on a structure.

iv. Some pipeline operators install galvanic anodes at each location where a leak is repaired rather than installing a complete cathodic.

Figure 3.2 shown the sacrificial anodes system. Figure 3.3 shown the electrochemical series.

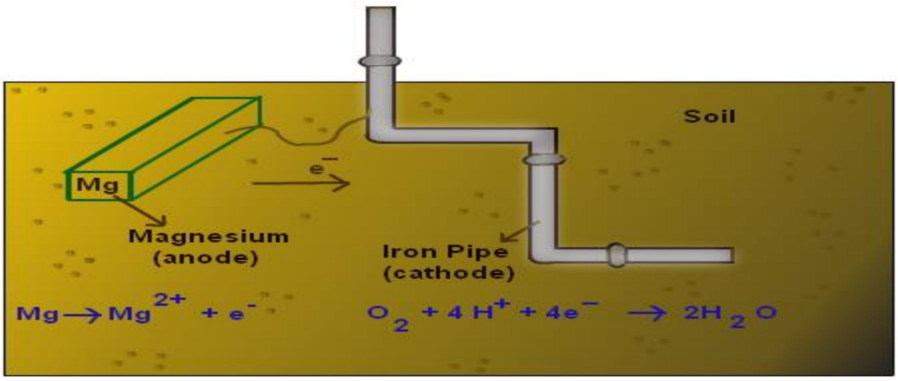

Figure 3.2: Sacrificial anodes system

Figure 3.3: Electro-Chemical Series

3.5 Design Cathodic Protection

In practice cathodic protection is designed according to:

3.5.1 Required information

Before deciding which type, galvanic or impressed current, cathodic protection system will be used and before the system is designed, certain preliminary data must be gathered.

i. Physical dimensions of structure to be protected.
ii. Drawing of structure to be protected.
iii. Electrical isolation.
iv. Short circuits Corrosion history of structures in the area.
v. Electrolyte resistivity survey.
vi. Structure versus electrolyte potential survey.
vii. Current requirement.
viii. Coating resistance.
ix. Protective current required.

x. The need for cathodic protection.[3]

3.5.2 Determining type and design of cathodic protection system

When all preliminary data have been gathered and the protective current has been estimated, the design sequence can begin. The first question to ask is: which type (galvanic or impressed current) cathodic protection system is needed? Conditions at the site sometimes dictate the choice. However, when this is not clear, the criterion used most widely is based on current density required and soil resistivity. If the soil resistivity is low (less than 5000 ohm-centimeters) and the current density requirement is low (less than 1 milliampere per square foot), a galvanic system can be used. However, if the soil resistivity and/or current density requirement exceed the above values, an impressed current system should be used.[3]

3.6 Impressed Current Cathodic Protection System Design

Designing iccp system consists of:

- Components of Impressed Current Cathodic Protection

  The components of an impressed current cathodic protection system are anodes, anode backfill, a power supply (rectifier), structure, wiring, and connections. The anodes used in impressed current CP systems are different from those used in galvanic systems. Impressed current anodes are manufactured from materials that are consumed at low rates. Impressed current CP systems generally operate at higher current and driving voltage levels than galvanic anode CP systems. [3]

- Anodes:
  - High-silicon chromium-bearing cast iron
  - Lead.
  - Mixed-metal oxide.
  - Platinum.

Impressed current anodes are installed either as distributed or remote anodes, anodes can be installed in surface ground beds (up to 7.62 m [25 ft.] deep). In addition, impressed current anodes are used in the remote configuration by installing them in a deep hole drilled from the surface. These are called 'deep anodes'. Deep anodes are at least 15.24 m (50 ft.) deep. Semi-deep anodes are 7.62 to 15.24 m (25 to 50 ft.) in depth. Deep anodes can be several hundred feet deep to achieve the remote anode configuration.

In the case of a buried pipeline or elongated structure, anodes can be placed parallel to a structure or perpendicular to the structure.

Parallel or distributed placement of the anodes results in the current being evenly distributed along the length of the structure. This configuration "closely couples" the anode to the structure and is useful in situations where the structure is not well coated or where other nearby structures might be subjected to interference. A parallel or distributed configuration might be needed if there is insufficient right-of-way for a remote anode bed. Perpendicular anode placement can be used where the structure is well coated, where current requirements are relatively low, and where property access permits. [3]

- Anode Backfill

Backfill is Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Carbon is used as a backfill material around impressed current anodes for underground CP applications. The purpose of the backfill material is to:

i. Reduce the resistivity of the environment surrounding the anode to increase the amount of current the anode can discharge.
ii. Extend the anode surface area, thus increasing the amount of current the anode can discharge.

iii. Reduce consumption of the anode since the carbon becomes the part of the anode consumed before the anode itself.

The resistance of carbon backfill is dependent on how well it is compacted, the higher the degree of compaction, the lower the resistance. The size of the carbon particles is important in compaction. A mixture of large and small sizes is advisable to attain good density and low resistance. The size range may be on the order of 0.5 to 12.7 mm (0.02 to 0.5 in.). Finer grade coke is often used for deep anode systems and the particles may range from 0.10 to 1 mm (0.004 to 0.04 in.) in size.[3]

- Reference electrode

An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

- Copper-Copper Sulfate Electrode

Copper sulfate reference electrodes (CSE) are the most commonly used reference electrode for measuring potentials of underground structures and also for those exposed to fresh water. It is not suitable for use in a chloride electrolyte as the chloride ions will migrate through the porous plug and contaminate the CSE. The electrode is composed of a copper rod, immersed in a saturated solution of copper sulfate, held in a non-conducting cylinder with a porous plug at the bottom, as shown in Figure 3.4, The copper ions in the saturated solution prevent corrosion of the copper rod and stabilize the reference electrode.

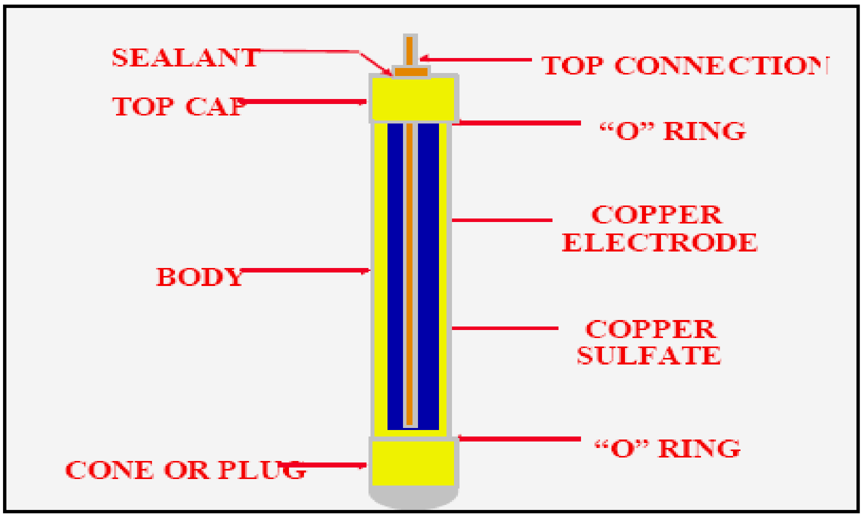

Figure 3.4: Copper-Copper Sulfate Electrodes

- Silver-Silver chloride reference electrode

Silver-silver chloride (Ag-AgCl) reference electrodes are used for measurements in seawater. The Ag-AgCl electrode is also used in concrete structures. There are two types; in one the silver electrode is exposed to seawater and in the other the electrode is immersed in a potassium chloride (KCl) solution contained in a cylinder with a porous plug. A correction is needed for readings taken with the first reference if not in pure seawater.[3]

- DC Power Sources

Depending on economics any source of DC power can serve as an impressed current power source and may consist of:

Transformer-Rectifier**:** The most common type of power supply used for impressed current cathodic protection is a transformer/rectifier, commonly referred to simply as a rectifier, a rectifier converts the AC power supply voltage to the required output voltage and then converts it to DC,the rectifier input is an AC voltage from the commercial electrical power grid or an engine-generator. A transformer with tap adjustments in the secondary side provides a method to reduce and adjust the output voltage level and to isolate the DC circuit from the input power system. A rectifying circuit next converts the adjusted AC voltage to produce a DC voltage output.

Solar Power Supplies**:** Figure 3.5 shows a solar power supply consisting of a solar panel, a charge controller, and a battery system, specially designed doped silicon semiconductors, which are photosensitive, convert solar energy to electrical energy, these semiconducting devices (photovoltaic cells) produce a voltage by absorbing energy from light photons striking the semiconductor and freeing electrons within the semiconductor. Solar panels are available in output voltages of 6, 12, and 24 V with power outputs ranging from 5 to 160 W, designers can also connect solar panels in series or parallel, as necessary, to produce an even larger output current or voltage, a backup battery system is necessary with a solar power supply to produce the required current output when solar energy is unavailable (night and overcast days).

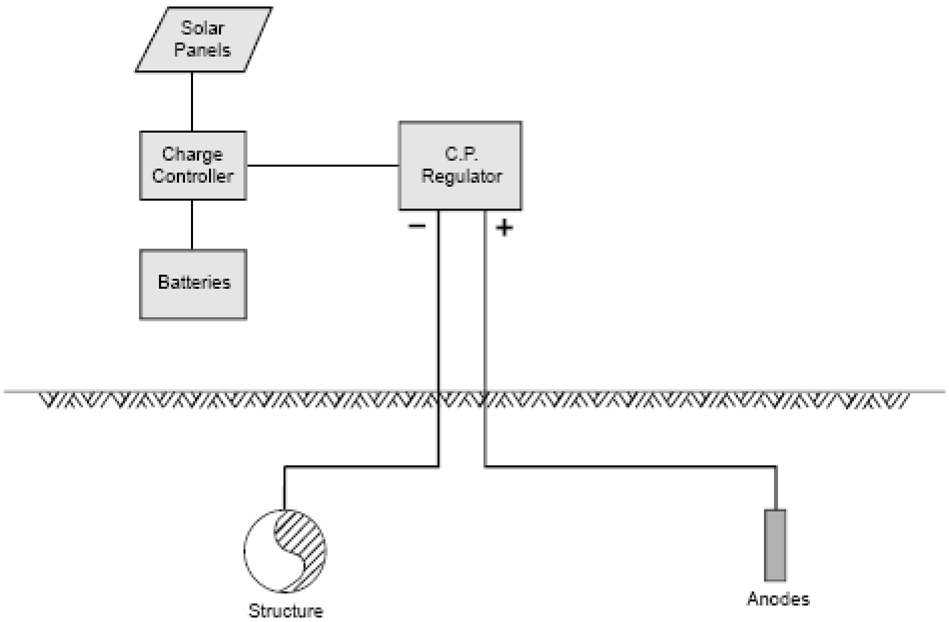

Figure 3.5: A solar power supply system for CP

CHAPTER FOUR

PRATICAL APPLICATION

4.1Introduction

The system was designed to control and monitoring cathodic protection station using microcontroller according to system operation, to improve the performance of station and make them permanently observed and the Possibility of detecting faults immediately.

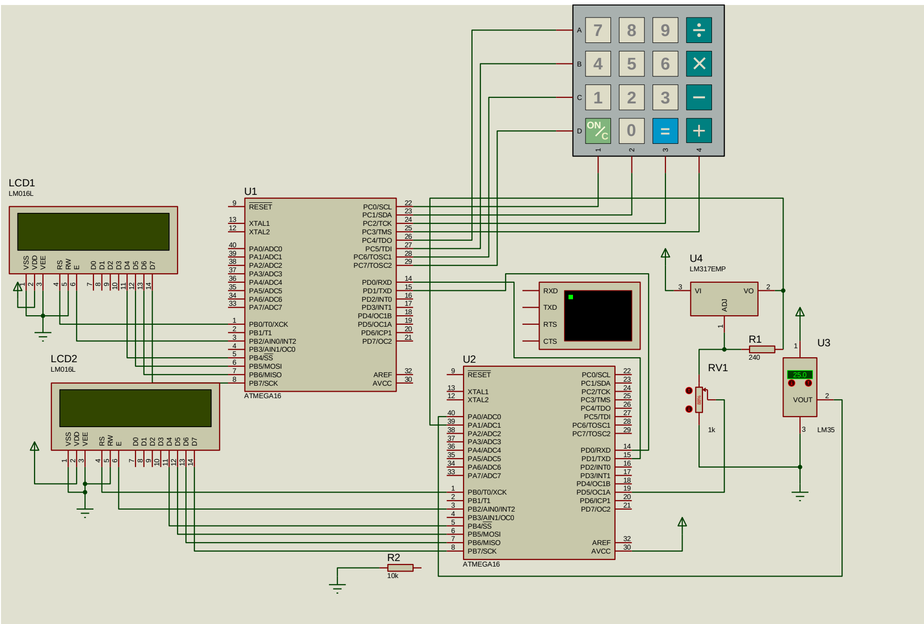

Figure 4.1: the system circuit

4.2 Circuit Components

The main components are:

4.2.1 Microcontroller ATmega16:

The ATmega16 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega16 achieves throughputs approaching 1 MIPS per MHz allowing the system’s designer to optimize power consumption versus processing speed. Figure 4.2 shown the micro controller atmega 16.

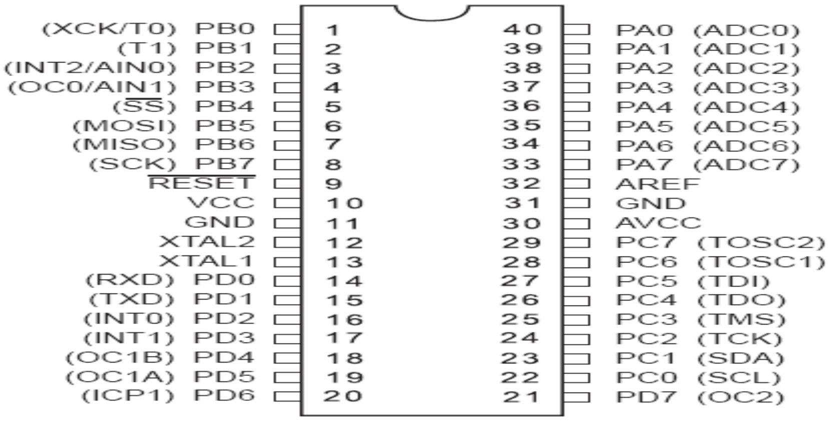

Figure 4.2: Microcontroller ATmega16

Table 4.1 shown the pin descriptions

Table 4.1: Pin Descriptions

VCC	Digital supply voltage.
GND	Ground.
Port A (PA7...PA0)	Port A serves as the analog inputs to the A/D Converter. Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port A output buffers have symmetrical drive characteristics with both high sink and source capability. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tri-stated when a reset condition becomes active, even if the clock is not running.
Port B (PB7...PB0)	Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.
Port C (PC7...PC0)	Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port

	C pins are tri-stated when a reset condition becomes active, even if the clock is not running. If the JTAG interface is enabled, the pull-up resistors on pins PC5(TDI), PC3(TMS) and PC2(TCK) will be activated even if a reset occurs.
Port D (PD7...PD0)	Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.
RESET	Reset Input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length is given in Table 15 on page 36. Shorter pulses are not guaranteed to generate a reset.
XTAL1	Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.
XTAL2	Output from the inverting Oscillator amplifier.
AVCC	AVCC is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to VCC, even if the ADC is not used. If the ADC is used, it should be connected to VCC through a low-pass filter.
AREF	AREF is the analog reference pin for the A/D Converter.

- Operating Voltages

  – 2.7 - 5.5V for ATmega16L

  – 4.5 - 5.5V for ATmega16

- Speed Grades

  – 0 - 8 MHz for ATmega16L

  – 0 - 16 MHz for ATmega16

4.2.2 LM317T variable voltage regulator

The LM317T is an adjustable 3 terminal positive voltage regulator capable of supplying in excess of 1.5 amps over an output range of 1.25 to 37 volts. The device also has built in current limiting and thermal shutdown which makes it essentially blow-out proof, output voltage is set by two resistors R1 and R2 connected as shown below. The voltage across R1 is a constant 1.25 volts and the adjustment terminal current is less than 100uA.

Which ignores the adjustment terminal current but will be close if the current through R1 and R2 are many times greater? A minimum load of about 10mA is required, so the value for R1 can be selected to drop 1.25 volts at 10mA or 120 ohms. Something less than 120 ohms can be used to insure the minimum current is greater than 10mA. The example below shows a LM317 used as 13.6 volt regulator. The 988 ohm resistor for R2 can be obtained with a standard 910 and 75 ohm in series. Figure 4.3 shown a variable voltage regulator.

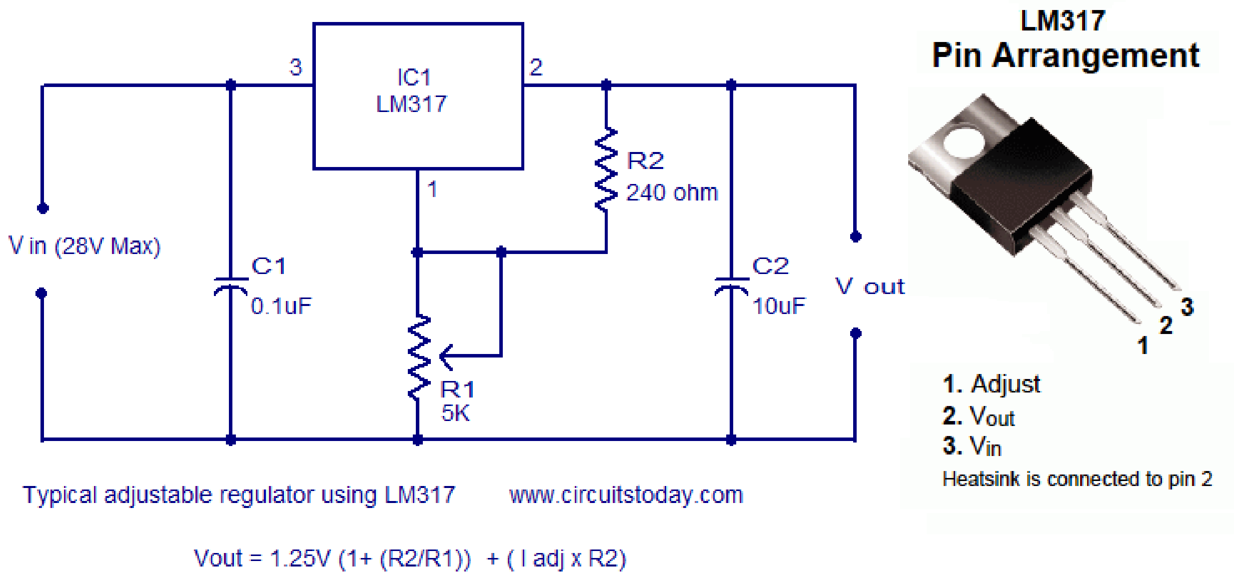

Figure 4.3: a variable voltage regulator

4.2.3 Low-cost low-power sub-1GHz RF transceiver

Is a low-cost sub- 1 GHz transceiver designed for very low-power wireless applications. The circuit is mainly intended for the ISM (Industrial, Scientific and Medical) and (Short Range Device) frequency bands at 315, 433, 868, and 915 MHz, but can easily be programmed for operation at other frequencies in the 300-348 MHz, 387-464 MHz and 779-928 MHz bands.

- The main improvements on the transceiver include:
- Improved spurious response
- Better close-in phase noise improving
- Adjacent Channel Power (ACP) performance
- Higher input saturation level
- Improved output power ramping

Figure 4.4 shown radio frequency transceiver

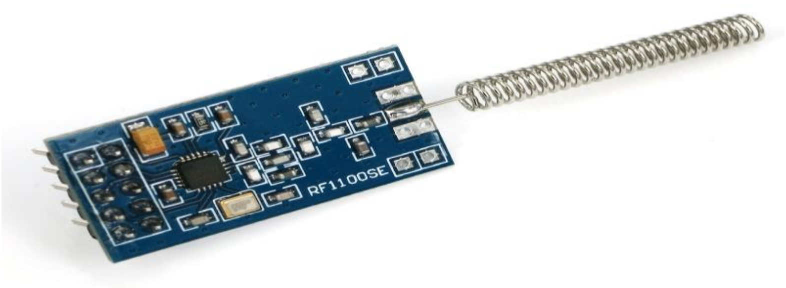

Figure 4.4: radio frequency transceiver

4.2.4 Two liquid crystal display LCDs 16*2:

A Liquid-Crystal Display (LCD) is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly; the LCD screen is more energy efficient and can be disposed of more safely than a cathode ray tube CRT. Its low electrical power consumption enables it to be used in battery-powered electronic equipment. It is an electronically modulated optical device made up of any number of segments filled with liquid crystals and arrayed in front of a light source (backlight) or reflector to produce images in color or monochrome. Liquid crystals were first discovered in 1888. By 2008, annual sales of televisions with LCD screens exceeded sales of CRT units worldwide, and the CRT became obsolete for most purposes. Figure 4.5 shown liquid crystal display

Figure 4.5: Liquid crystal display

4.2.5Keypad

A keypad is a set of buttons arranged in a block or "pad" which usually bear digits, symbols and usually a complete set of alphabetical letters. If it mostly contains numbers then it can also be called a numeric keypad. Keypads are found on many alphanumeric keyboards and on other devices such as calculators, push-button telephones, combination locks, and digital door locks, which require mainly numeric input.

4.3 System operation

The main data of the pipelines to be protected are as provided by the following table:

Table 4.2: Data of the Pipelines

Pipeline	Diameter [m]	Length [m]	Pipe Material	Product	Max operating temperature [°C]	Coating
KRC to MADANI	0.3239	216000	Carbon Steel API 5L X60/X65 Wall thickness 6.4	Kerosene /Gasoil/Mogas	70	3LPE/3LPP

Based on relevant specification and research documentations, the following parameters have been

Considered in the design calculations:

• Protection current density of buried pipes for permanent protection: Is =0.05 mA/m2.

• Protection current density of buried pipes for temporary protection: Is =0.01 mA/m2.

• Soil resistivity (maximum soil resistivity at 3 meter depth in all ground beds locations): 100 Ohm.m.

• Resistivity of steel pipe: 18 e-7 Ohm.m

• Insulation resistance for Polyethylene/Polypropylene coating: 30000 Ohm.m^2

• Minimum protection potential: -0.85 V.

• Drain point potential: -1.15 V.

• Design life: 25 years for PCP system.

4.3.1 DESIGN CALCULATION

CURRENT REQUIREMENT: The protection current can be calculated by using the formula below:

$$I = \pi \times D \times L \times Is \quad (4.1)$$

Where:

D : Outside diameter of pipeline (m)

L : Length of pipeline (m)

Is : Current density (A/m2)

A margin factor of 40% will be considered for the calculation of the current requirement:

Table 4.3: Current Requirement Calculation Results:

Pipeline	Diameter [m]	Total Surface [m^2]	Current Requirement [A]	Current Requirement after 40% Allowance[A]
KRC to MADANI	0.3239	219794	10.99	15.386

4.3.2 Pipelines attenuation calculation and protective length

- Attenuation: Attenuation usually depends on the type of external coating and the lineal resistance of the pipeline. A high quality coating will result in better protection spread. If Cathodic Protection current is impressed to a Pipeline, the length of a pipeline that may be protected may be protected from a single cathodic protection station (in each direction from the drain point) can be calculated using the following equation:

- Pipeline lineal resistance:

The calculation formula for longitudinal resistance of pipeline:

$$RI = (Rs * 1000)/ (\pi * (D - s) *s) \qquad [Ohm/ Km] \qquad (4.2)$$

Where:

Rs : steel specific resistivity (Ohm. m)
D : Outside diameter of pipeline (m)
S : Wall thickness of pipe (m)

- Coating leakage resistivity (Rt):

The calculation formula:

$$Rt = Ri / (\pi * D * 1000) \ [Ohm. Km] \qquad (4.3)$$

Where:

Ri : insulation resistance for Polyethylene/Polypropylene coating 25 years old (Ohm.m^2).

The coating conductance is a measure of the conductivity of the coating per unit length and is usually calculated from an estimate of the coating resistance. This is because there is virtually no published data on the resistance of commercially available coatings and very few specifications that actually quote real values. A value of 30000 Ohm.m2 has been considered for PE/PP coating for 25 years design life.

- Attenuation coefficient:

The calculation formula for attenuation coefficient of pipeline:

$$\alpha = \sqrt{\frac{RI}{Rt}} \quad (4.3)$$

Where:

RI : Pipeline lineal resistance

Rt : Coating leakage resistivity

Table 4.4: Attenuation Coefficient Calculation Results:

Pipeline	Diameter [m]	Wall thickness [m]	Lineal resistance [Ohm/ Km]	Coating resistance [Ohm. Km]	Attenuation coefficient [Km^{-1}]
KRC to MADANI	0.3239	6.4	0,0282	29,48	0,0309

- Protective Length:

  The calculation formula for protected length of pipeline:

$$L_{\max} = \frac{1}{\alpha} Ln\left(\frac{\Delta U_S}{\Delta U_0} - \sqrt{\left(\frac{\Delta U_S}{\Delta U_0} \right)^2 - 1} \right) \quad (4.4)$$

Where:

α : Attenuation coefficient of pipeline

ΔU_s : Change in pipeline potential at drain point due to application of impressed current

ΔU_0 : Change in pipeline potential at a point at distance L_{max} due to application of impressed current.

U_0 : Pipeline native potential (-0.5V for steel).

$\Delta U_s = -1.15 - (-0.5) = -0.65V$

$\Delta U_0 = -0.85 - (-0.5) = -0.35V$

Table 4.5: Maximum Length of Protection Calculation Results

Pipeline	Diameter [m]	Attenuation coefficient [Km^{-1}]	Protective length from each side of source [Km]
KRC to MADANI	0.3239	0,0309	39.78

4.3.3 Optimum Number of CP Stations

Based on attenuation calculation and for economical (on the installation work) and safety reason, the length of multiproduct pipeline is approximately 216 km, so five cathodic protection stations are designed at: KRC (CP Station#1), at Block valve BV2 (CP Station#2), at Block valve BV3 (CP Station#3), at Block valve BV4 (CP Station#4), and at Block valve BV5 (CP Station#5).

- Source of Power

CP Station#1will work under an AC Supply 400VAC, 50Hz (a transformer-rectifier will be used) as the availability of electrical power, while CP Station#2, CP Station#3, CP Station#4 and CP Station#5, will work under DC supply by Solar power generator with accumulator batteries.

4.3.4 ANODES REQUIREMENTS:

At the initial CP station#1 (at Khartoum KRC), CP station#2 and CP station#3, a deep well anode bed consisting of high silicon cast iron anodes shall be installed due to the high soil resistivity. The size of each anode shall be 38 mm (Dia) x 1500 mm (Length). Each anode will be provided with 1 x16 mm^2 cables; a carbonaceous coke breeze will be filled in the groundbed to form a low resistance active anode column.

Each anode shall be terminated individually to the anode junction box.

At CP station#4 and CP station#5, a shallow horizontal anode bed consisting of high silicon cast iron anodes shall be installed. The size of each anode shall be 38 mm (Dia) x 1500 mm (Length). Each anode will be provided with 1 x16 mm2 cable. Each anode will be installed horizontally with coke breeze will be filled in the groundbed to form a low resistance active anode column.

4.3.5 Calculation of Output Current of Each Groundbed:

In order to provide a safety factor (consider 40% spare capacity), a minimum current is to be made available for the Permanent Cathodic Protection System:

The minimum current output of each station shall be as follow:

Table 4.6: Current Requirement for Each CP Station

Station	Location	Min Current [A]
CP Station#1	Khartoum KRC	1.54
CP Station#2	BV2 (at 42.6 km from KRC)	3.16
CP Station#3	BV3 (at 84.6 km from KRC)	3.16
CP Station#4	BV4 (at 132.3 km from KRC)	3.16
CP Station#5	BV5 (at 177.2 km from KRC)	4.36

- Calculation of Anodes Quantities:

Calculation formula of anode total number:

$$N = \frac{y * c * i}{u * w} \tag{4.5}$$

Where:

y: Design life (years); Y=25 years.

c: Consumption rate (Kg/A year); C=0.35 Kg/A year.

u: Utilization factor; U=0.75.

i: Minimum Current requirement (A).

w: weight of one anode (Kg); W=13 Kg.

Hence Calculation of minimum quantity of anode in each anode bed:

Table 4.7: Minimum Number of Anodes for Each CP Station

Station	Min Current [A]	Number of anodes
CP Station#1	1.54	2
CP Station#2	3.16	3
CP Station#3	3.16	3
CP Station#4	3.16	3
CP Station#5	4.36	4

Hence the minimum numbers of anodes required to meet each CP system current requirement. However it is proposed to install 4 nos. anodes in each anode bed to reduce the grounding resistance of anode bed.

4.3.6 GROUNDING RESISTANCE:

Groundbed is utilized for the induction of current into the surrounding environment to allow the current to reach the structure to be protected. The resistance of the groundbed to the surrounding environment has an overall effect on the size of the cathodic protection system.

This groundbed resistance to the environment is dependent on a number of factors:

- Type of groundbed i.e. horizontal, vertical, and shallow/deep well.
- Number of anodes utilized.
- The anode diameter and length.
- Spacing between anodes.
- Depth of groundbed
- Use of inert backfill material to lower the interface resistance between the anode and the environment electrolyte (soil/sand), and hence the overall groundbed to environment resistance.
- Environment resistivity

Total resistance of each anode to earth consists of the resistance of the anode to the carbonaceous backfill plus the resistance to earth of the backfill column itself.

- Groundbed Resistance for Shallow Horizontal Groundbed:

The anodes will be installed in a horizontal groundbed filled with carbonaceous backfill which will have a rectangular section (30 cm width; 30 cm thickness), the distance between anodes is 3.5 meter Centre to Centre.

Therefore, using the Dwight's Equation for Multiple Anodes Installed Horizontally, the resistance can be calculated as follows:

$$Rg = \frac{0.00159 \ * \rho}{L} \ (ln\frac{4L^2 + 4L\sqrt{L^2+S^2}}{dS} + \frac{S}{L} - \frac{\sqrt{L^2+S^2}}{L} - 1) \qquad (4.6)$$

Where:

ρ : resistivity of soil (ohm.cm); ρ=10.000 ohm.cm

L : Total Length of ground bed (m);

L = 14 m. (1.5x4 +2x3 +1 +1), Anodes spacing =2m.

d : Equivalent Diameter of groundbed section (m); d=0.328 m

S : Twice depth of anode groundbed (m); S =6 m

- Ground bed Resistance for Deep well ground bed:

As above calculation a minimum of 3 nos. anodes are required for each CP station to meet the CP system current requirement.

- Anode to Backfill Resistance Ra:

Therefore, using the Dwight's Equation for Multiple vertical anodes, the resistance can be calculated as follows:

$$Ra = \frac{0.00159 \ * \rho}{NL} \ (ln\frac{8\,L}{d} - 1 + \frac{2\,L}{S} \ ln\, 0.656\, N) \qquad (4.7)$$

Where:

ρ : resistivity of backfill material; ρ= 50 ohm.cm

L : Length of anode (m); L=1.5m

d : Diameter of anode (m); d=0.038m

N : Number of anodes in parallel; N=4

S : Anodes spacing (m); S=3m.

Backfill column to earth resistance: Rb:

Therefore, using the Dwight's Equation for single vertical anode, the resistance can be calculated as follows:

$$Rb = \frac{0.00159 \ * \rho}{L} \ (ln \frac{8\,L}{d} - 1) \tag{4.8}$$

Where:

ρ : resistivity of soil (ohm.cm); ρ=2000 ohm.cm (will be adopted as maximum value, the depth of inactive column depends on water table level)
L : Length of active column of deep groundbed (m); L=18 m (4x1.5+3x3+1.5+1.5)
d : Diameter of deep groundbed (m); d=0.203m (8 in)

Anode to earth total resistance Rg:

The grounding resistance of anode ground bed is:
Rg = Ra+Rb (4.9)

- Calculation Result:

Table 4.8: Resistance Calculation Results:

Station	Min Current (A)	Number of anodes	Ra (ohm)	Rb (ohm)	Rg (ohm)
CP Station#1	1.54	4	0.11	1	1.11
CP Station#2	3.16	4	0.11	1	1.11
CP Station#3	3.16	4	0.11	1	1.11
CP Station#4	3.16	4	-	-	3.15
CP Station#5	4.36	4	-	-	3.15

4.3.7 Positive and negative header cable resistance (RH):

Positive header cable from DC power source unit to the anode junction box (AJB) shall be provided; the distance of the AJB from the DC power unit is estimated at 175 meters.

Negative header cable shall be provided from DC power source unit to the pipe structure (Drain point).

The estimated cable length from the DC power unit to the pipe structure is estimated at 25 meters.

The resistance of cable 1 x 35mm² is 0.524 ohm/km. The total length of positive cable and negative cable is 200m.

Rh = 0.2 x 0.524

Rh= 0.1048 ohm

- TOTAL CIRCUIT RESISTANCE:

The total circuit resistances (R) shall be the sum of the groundbed resistance to earth (Rg) and the total cable resistances (Rh).

Table 4.9: Total Circuits Resistance Calculation Results

Station	Min Current (A)	Number of anodes	Rg (ohm)	Rh (ohm)	R (ohm)
CP Station#1	1.54	4	1.11	0.1048	1.21
CP Station#2	3.16	4	1.11	0.1048	1.21
CP Station#3	3.16	4	1.11	0.1048	1.21
CP Station#4	3.16	4	3.15	0.1048	3.25
CP Station#5	4.36	4	3.15	0.1048	3.25

4.3.8 RATING OF DC POWER UNIT:

The ICCP system requires a permanent source of power that will supply a direct current and voltage. The DC output shall be rated to meet current and resistance requirements.

The voltage output is determined by using Ohm's Law:

V (voltage) = I (current required) x R (total circuit resistance)

The final DC voltage output shall be the calculated as voltage required plus back EMF (2 volts in the case of carbonaceous backfill).

Table 4.10: CP Stations Ratings

Station	Number of anodes	Min Current (A)	R (ohm)	Voltage (V)
CP Station#1	4	1.54	1.21	3.86
CP Station#2	4	3.16	1.21	5.82
CP Station#3	4	3.16	1.21	5.82
CP Station#4	4	3.16	3.25	12.27
CP Station#5	4	4.36	3.25	16.17

- DETERMINATION OF DC POWER SPECIFICATION:

ln consideration of factors, such as greater cathodic protection current will be required at initial polarization stage for pipeline, on the other hand, grounding resistance of anode bed will be increased in dry season and along with the time extension, the capacity of TRU / solar CP controller unit shall be designed with sufficient surplus and may accommodate any unforeseen increases in anode grounding resistance. Therefore, for the sizing of proposed TRU / solar CP controller unit, the rated output current will be 5A and the rated output voltage will be 24V for each one.

4.4.9 BACKFILL REQUIRED

The total volume of Coke Breeze backfill column can be calculated as under:

Wcb = Volume of backfill x Density of coke breeze x 120%

$$\text{Volume of backfill } (V) = \pi \left[(D^2/4)\,H - N\,(d^2/4)\,L\right] \qquad (4.10)$$

Where:

Wcb: Weight of Coke Breeze backfill (Kg)

H: Depth of backfill column (m)

D: Diameter of backfill column (m)

d : Diameter of anode (0.038m)

L: Length of anode (1.5m)

N: Number of anodes

120%: Allowance for settling

Density of "Calcined Petroleum" Coke Breeze backfill is 1200 Kg/m3

(As per manufacturer data sheet), therefore:

Wcb = V x 1.2 x 1200

Table 4.11: Backfill weight

Station	Number of anodes	Total coke weight (Kg)
CP Station#1	4	830
CP Station#2	4	830
CP Station#3	4	830
CP Station#4	4	1937
CP Station#5	4	1937

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Corrosion cost of the soil industry is very high. Oil industry faces corrosion problems at various stages, including oil wells, transportation, and storage and refinery operations.

That's one of the largest expenditures we make, and it's all going down the drain. The total annual corrosion costs in the U.S. rose above $1 trillion in the middle of 2013, illustrating the broad and expensive challenge that corrosion presents to equipment and materials. The most commonly quoted figure for corrosion costs is $276B in 1998 and was reported in the NACE Corrosion Costs Study. However, this report leaves out the enormous (at least as much as direct costs) tally of indirect costs that the consumers experience from corrosion and the inflation increases since 1998.

The design controlled the pipelines corrosion by means control, monitoring of stations.

5.2 Recommendations

- Design can be done by means of Plc control and scada system to give better control and monitoring.
- Making data base system to appraise the performance of protection (schemes, graphs …etc).
- Design a Sacrificial anodes system.
- Study the other usages of cathodic protection and the other methods to protect from corrosion.

REFERENCES

[1] Baeckmann, W. von, Schenk, W. and Prinz W., Edts “Handbook of cathodic corrosion protection”, Third Edition, Gulf Publishing Company, 1997.

[2] A.W. Peabody, “Peabody's Control of Pipeline Corrosion”, 2nd Ed., NACE International, 2001.

[3] Marshall E. Parker, “Pipe line corrosion and cathodic protection”, Gulf Publishing Company,1999.

APPENDEX

The program code:

- Rx code**:**

```
$regfile = "m16def.dat"

$regfile = 8000000

$baud = 4800

Config Lcd = 16 * 2

Config Lcdpin = Pin , Db4 = Portb.4 , Db5 = Portb.5 , Db6 = Portb.6 , Db7 = Portb.7 , E = Portb.2 , Rs = Portb.0

Config Adc = Single , Prescaler = Auto , Reference = Avcc

Config Timer1 = Pwm , Pwm = 8 , Compare A Pwm = Clear Down , Compare B Pwm = Clear Down , Prescale = 64

Cls

Locate 2 , 5

Lcd "NO DATA"

Wait 1

Cls

1:

Do

T1 = Getadc(1)

   Temp1 = T1

  Temp1 = Temp1 / 100
```

```
Cls

Cursor Off

Config Portc.0 = Output

Dim T As Word

Dim Temp As Single

Dim T1 As Word

Dim Temp1 As Single

Dim X As Byte

Dim S As String * 64

Dim V As Byte

Dim N As Byte

Dim L As Byte


   Temp1 = Round(temp1)

   Waitms 100

T = Getadc(0)

   Temp = T

   Temp = Temp / 100

   Temp = Round(temp)

   Waitms 100

Locate 1 , 1

Lcd "VD: " ; Temp

Waitms 200
```

```
Locate 2 , 1
Lcd "VR: " ; Temp1
Wait 2
Goto 2
Loop

S = ""
2:
Do
Do
X = Waitkey()
If X = &H2A Then Exit Do
If X <> 13 Then
If X <> 10 Then
S = S + Chr(x)
End If
End If
Loop
Cls
Locate 1 , 1
Lcd S
'S = ""
Wait 2
Print Temp ; "*"
Wait 2
Goto 3
Loop
3:
Do
If Temp = Temp1 Then
Portc.0 = 0
Else
Portc.0 = 1
End If

If S = "5" Then
Compare1a = 255
Compare1b = 0
Temp1 = 5
S = ""
Goto 1
End If
If S = "4" Then
Compare1a = 204
Compare1b = 0
Temp1 = 4
S = ""
Goto 1
End If
If S = "3" Then
```

```
Compare1a = 153
Compare1b = 0
Temp1 = 3
S = ""
Goto 1
End If
If S = "2" Then
Compare1a = 102
Compare1b = 0
Temp1 = 2
S = ""
Goto 1
End If

If S = "1" Then
Compare1a = 51
```

- Tx code:

```
$regfile = "m16def.dat"
$regfile = 8000000
$baud = 4800
Config Lcd = 16 * 2
Config Lcdpin = Pin , Db4 = Portb.4 , Db5 = Portb.5 , Db6 = Portb.6 , Db7 = Portb.7 , E = Portb.2 , Rs = Portb.0
```

```
Compare1b = 0
Temp1 = 1
S = ""
Goto 1
End If
If S = "0" Then
Compare1a = 0
Compare1b = 0
Temp1 = 0
S = ""
Goto 1
End If
If S = "13" Then
Goto 1
End If
Loop
    Cls
    Cursor Off
    Config Kbd = Portc

    Dim B As Byte
    Dim C1 As Word
    Dim D As Byte
    Dim P As Byte
    Dim S1 As Byte
```

```
Dim M As Byte
Dim X As Byte
Dim S As String * 14
First:
Do
M = Getkbd()
If M <> 16 Then Gosub Calculation
Waitms 20
Locate 2 , 5
Lcd C1
Wait 1
If D = 1 Then
Print C1 ; "*"
Waitms 5
C1 = 0
D = 0
Cls
Goto M1
End If
Loop
S = ""
M1:
Do
Do
X = Waitkey()

If X = &H2A Then Exit Do

If X <> 13 Then
If X <> 10 Then
S = S + Chr(x)
End If
End If
Loop
Cls
Locate 1 , 1
Lcd "value Vd"
Locate 2 , 1
Lcd S
S = ""
Wait 1
Goto First
Loop
Calculation:
S1 = Lookup(m , Dta)
Incr D
P = D + 6
C1 = C1 * 10
C1 = C1 + S1
```

Waitms 200

Return

Dta:

Data 15 , 14 , 0 , 13 , 12 , 9 , 8 , 7 ,
11 , 6 , 5 , 4 , 10 , 3 , 2 , 1