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Cathodic Protection Remote Monitoring Based on Wireless Sensor Network

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ABSTRACT

Cathodic Protection system is an efficient system used for protecting the underground metal objects from corrosion. In this paper the use of Cathodic Protection (CP) system and how they can be developed to simulate corrosion control solution was illustrated. The aim of developing a Cathodic Protection system is to provide control over oil pipelines and to reduce the incidence of corrosion. The proposed system integrates the technology of wireless sensor Network (WSN) in order to collect potential data and to realize remote data transmission. In this system each WSN receives the data from the environment and forwards it to a Remote Terminal Unit (RTU). Then each RTU forwards it to its base station (BS). In this work Labview 2010 program was used, due to its high potentials. In addition it contains a Tool Kit that supports the wireless sensor network. In this simulation used many cases study to test and monitoring data and get optimum results, least time delay and high speed to prevent corrosion.

Keywords: Cathodic Protection System; Corrosion; Wireless Sensor Network; Remote Terminal Unit

1. Introduction

Cathodic protection is a method of corrosion control that can be applied to buried and submerged metallic structures. It is normally used in conjunction with coatings and can be considered as a secondary corrosion control technique. The primary corrosion control method on any given structure is normally a coating system which can be between 50% and 99% efficient depending upon age, type, method of installation, etc. A properly designed and maintained Cathodic protection system will take up the remainder resulting in a 100% efficient corrosion protection system [1].

There are two methods for Cathodic Protection these methods are Cathodic Current and Sacrificial Anode.

The principle of Cathodic protection is to connect an external anode to the metal to be protected and to pass a positive DC current between them so that the metal becomes Cathodic and does not corrode [2].

Cathodic protection has become a standard procedure for many structures such as underground storage tanks, pipelines, water storage tanks, ship hulls and interiors [3].

Corrosion is an electrochemical process that occurs when a current leaves a structure at the anode side, passes through an electrolyte (it is generally soil in buried metal pipeline), and reenters the structure at the cathode side, also known as oxidation [4].

The field of wireless sensor Network is gaining a rapid interest due to the application of smart low cost long battery life sensors. Usually sensor Network consist of the sensors as end devices, routers to choose the most appropriate path to an administrator host that is called the coordinator [5].

Many papers studied this problem like [6,7], in these paper Cathodic protection systems were discussed for water storage tanks, short distance, periodically tested, using voltmeter device to measure the voltage between the poles. In these systems, it is required the maintenance team to go down to the site in addition to high cost and time delay. While our paper proposed the wireless device use instead of voltmeter device. The proposed system helps the operator to observe the results of all sensors remotely from the monitor in the control room as well as reduce the overall cost and time delay.

In this paper, a new method was suggested handling the problem by CP for WSN and also used Labview simulator 2010 for emulated this method.

2. Cathodic Protection Methodology

Corrosion is an electrochemical process that involves passage of electrons from one substance, usually metallic, called the anode, to another substance called the cathode. It is at the anode that the oxidation reaction which is responsible for corrosion of the metal shows in the **Figure**

1(a) [8]. Show the following equations [3]:

$$2M \rightarrow 2M^{+} + 2e^{-} \quad (1)$$

where: M = metal; M^{+} = soluble salt; e^{-} = electron.

The basic process at an anodic site is the release of iron (Fe) from the steel surface into the environment and can be expressed as [8]:

$$\mathrm{Fe} \rightarrow \mathrm{Fe}^{+2} + 2e^{-} \quad (2)$$

During the process two electrons ($2e^{-}$) are generated which must be consumed by the environment (in aerated systems) and can be expressed as [1]:

$$4\mathrm{H}^{+} + \mathrm{O}_2 + 4e^{-} \rightarrow 2\mathrm{H}_2\mathrm{O} \quad (3)$$

This reaction produces free electrons, which pass within the metal to another site on the metal surface (the cathode), where it is consumed by the Cathodic reaction. In acid solutions the Cathodic reaction is [3]:

$$2\mathrm{H}^{+} + 2e^{-} \rightarrow \mathrm{H}_2 \quad (4)$$

In neutral solutions the Cathodic reaction involves the consumption of oxygen dissolved in the solution Show in **Figure 1(b)** [8]:

$$\mathrm{O}_2 + 2\mathrm{H}_2\mathrm{O} + 4e^{-} \rightarrow 4\mathrm{OH}^{-} \quad (5)$$

Corrosion thus occurs at the anode but not at the cathode (unless the metal of the cathode is attacked by alkali).

A summary of the above half reactions can be expressed as [1]:

$$2\mathrm{Fe} + 2\mathrm{H}_2\mathrm{O} + \mathrm{O}_2 \rightarrow 2\mathrm{Fe}(\mathrm{OH})_2 \quad (6)$$

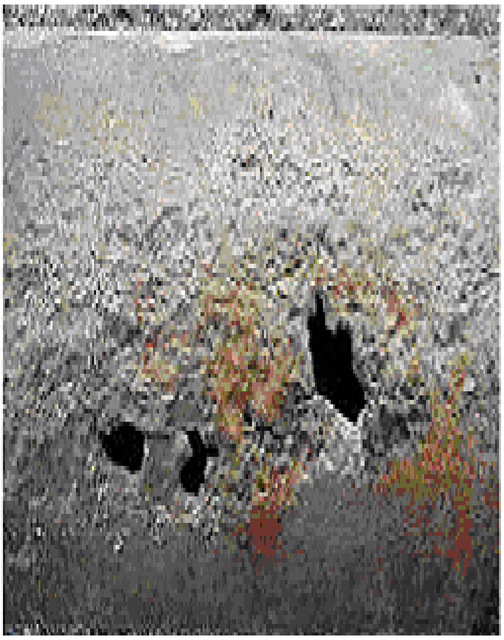
The term $\mathrm{Fe}(\mathrm{OH})_2$ is iron oxide which can be oxidised to form the red-brown $\mathrm{Fe}(\mathrm{OH})_3$ commonly referred to as rust.

Cathodic protection is an electrical method of preventing corrosion on metallic structures which are in electrolytes such as soil or water [6]. Therefore, it is necessary to control the corrosion of well casings for prevention of oil pipeline that can lead to environmental damage. Corrosion protection also ensures optimum economical depletion of oil reservoirs. The most effective method to decrease corrosion of well casings is the use of Cathodic Protection [9].

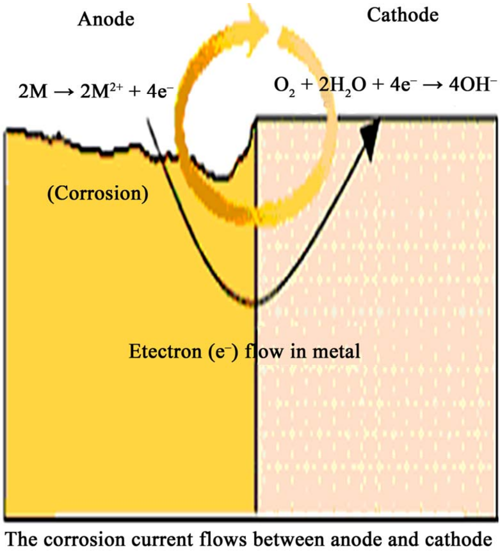
Advantage of Cathodic Protection methods is easy to install, no power source is required due to the fact that the protective current is generated by the electrochemical reaction between the metals, no externally supplied power is required, suitable for localized protection, minimum of maintenance required, no regulation is required, minimum of Cathodic interferences problems.The disadvantages of the Cathodic Protection include is small driving voltage available (the limited driving potential between the structure and the anode materials used), extremely small current available in higher resistivity electrolytes , not economically feasible to install or replace anodes on large or extensive existing structures, installation can be expensive if installed after construction [10].

3. The Suggested Monitoring System

The Remote Monitoring of Cathodic protection system based on wireless Sensor model is one of the most effective, convenient and economical methods to prevent corrosion. Design changes can achieve the optimum performance of Cathodic protection systems, preventing the impact of corrosion.



(a)



(b)

Figure 1. (a) Corrosion effects on pipelines; (b) Corrosion process.

The basic node of any WSN is the sensor node. The sensor node presented in this work consists of many basic parts such as: a sensing unit, a microcontroller, channel (transceiver), and battery as shown in **Figure 2(a)**. The sensing unit is a sensor inputted to an analog to digital converter (ADC) block embedded in the microcontroller. The communication unit is transceiver suitable for converting the signals of the microcontroller to the signal.

In this paper, we used a hierarchical architecture consisting of a sensor node, a gateway (RTU), and a base station. Sensor node that is responsible for monitoring the physical environment placed at the lowest level of the hierarchy. The designed network architecture of this work is illustrated in **Figure 2(b)**.

Wireless Sensor Network was used instead of the voltmeter for CP, where connected these devices with the parties to the anode and cathode of Cathodic protection, and then installed these devices the ground at a distance of one meter from the Oil pipeline, and the distance between two Wireless Sensor 2 km. The work of these devices is to collect data in the form of analog signal and convert them into digital signal and sent to the RTU and after gathering information from all wireless sensor devices, then all RTU stations send them to the base station to monitor and test data and give the result on the monitoring form. In **Table 1** the Remote Monitoring used many technologies.

4. Problem Section

The oil pipelines exposed continuously to corrosion or rust due to external factors from environment and to reduce this problem. Cathodic protection methods are used to prevent corrosion. These methods are preventing access of electrolyte, reversing the flow of electrons, corrosion resistance alloys like stainless steel. The method is widely used in underground and seawater structures.

The principle of Cathodic protection consists in the connection of an external anode to the metal to be protected and the passing of an electric current so that all areas of the metal become Cathodic and therefore not corrode. In electrochemical terms, the electrical potential between the metal and the electrolyte solution with which it is in contact is lowered to a value at which corroding anodic reactions are stifled and only Cathodic reactions can take place [12].

Both anode and cathode connected with wireless sensors. Anode connected with the positive from wireless and cathode connected with the negative from wireless sensor. Then the wireless sensor collected the data from environment through the difference voltage between the anode and cathode and sends it to remote terminal unit. Then the remote terminal unit forwards data to base station (control room) and here the process of the control data examine and make it update each time period according to the location and significance.

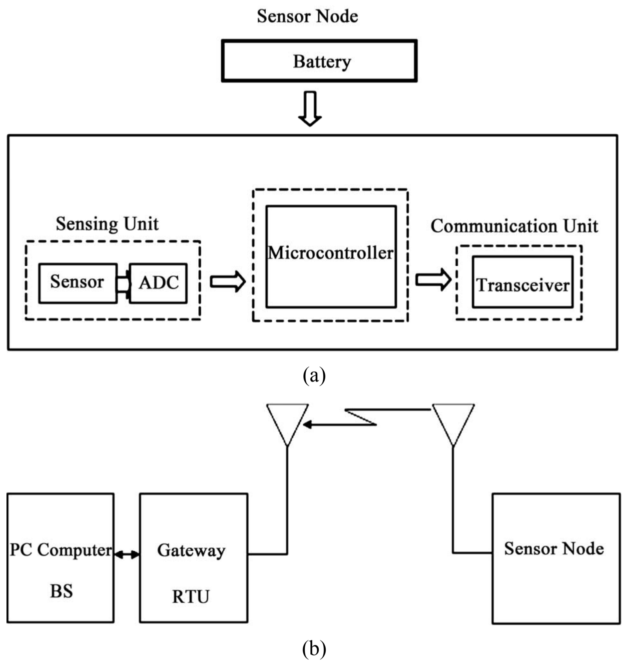


Figure 2. (a) Block diagram of Wireless Sensor [11]; b) Block diagram of the proposed network architecture designed for data acquisition [11].

Table 1. Comparison of Cathodic Protection Remote Monitoring Technologies.

Complexity	SCADA-Based System	Satellite-Based System	Cell phone-Based System
	High	High	Low
Advantages	—Takes advantage of existing wireless system —can take readings at any time —can control	—Monitor CP system virtually any time, anywhere in the world through the internet	—Low installation cost —can easily be installed —can take readings at any time
Disadvantages	—Signal path must be properly planned for adequate transmission Signals must be line of site(LOS) —Signals are sometimes lost if there are impediments to LOS	—Charges fee/reading/location —Line of site limitations	—Cost of cell phone services —Cell phone signals are sometimes lost in certain locations

5. Case Study

As an example a Cathodic protection methodology is considered for the Oil pipelines. In this method the cathode and anode are buried under the ground in a distance of two meters. Both cathode and anode are connected to the wireless sensor. This sensor is installed in one meter from the Oil pipeline and the distance between each two sensors of WSN is two kilometers. The data are collected from the environment by wireless sensor and sent to the RTU. Each RTU collection data from range about 50 kilometers and then forward to base Station. The distance between RTU and Base Station is 100 kilometers.

In this simple example nine wireless sensor devices, three RTU and Base Station. Each RTU included three wireless sensors. This Wireless Sensor was collected data from environment and sends it to RTU and then the RTU forwards data to base station in order to conduct testing and monitoring them by using Labview simulation program.

6. Simulation & Result

The proposed algorithm was simulated in a Labview 2010 simulation program. Depended on Standard Colamer Electric (SCE) to testing the data Acquisition.

6.1. Sensor Side of WSN

The flow chart of the sensing program is shown in **Figure 3**. **Figure 4** shows the measurement sequence. First the sensor side is initialized by setting the service port number and defining the IP Address of the gateway (RTU). After that it starts a timer for the TCP listen block. This block obtains TCP packets from gateway (RTU) in the range of around 50 km. Furthermore this operation depends on the IP address obtained in the beginning of the process. The duration of this step is chosen to be (6 sec.). Each sensor sends its data to the RTU within 2 seconds. After 6 seconds the communication between the RTU and sensors is terminated. Next new sensors start to communicate with the other RTUs. After (6 sec.) the RTU will close the TCP connection. Otherwise it resets the timer and then it uses TCP write block command to write the forward packet data to the RTU. The Sensor program continues to send packets to the gateway unless a manual stop action is initiated from the Sensor.

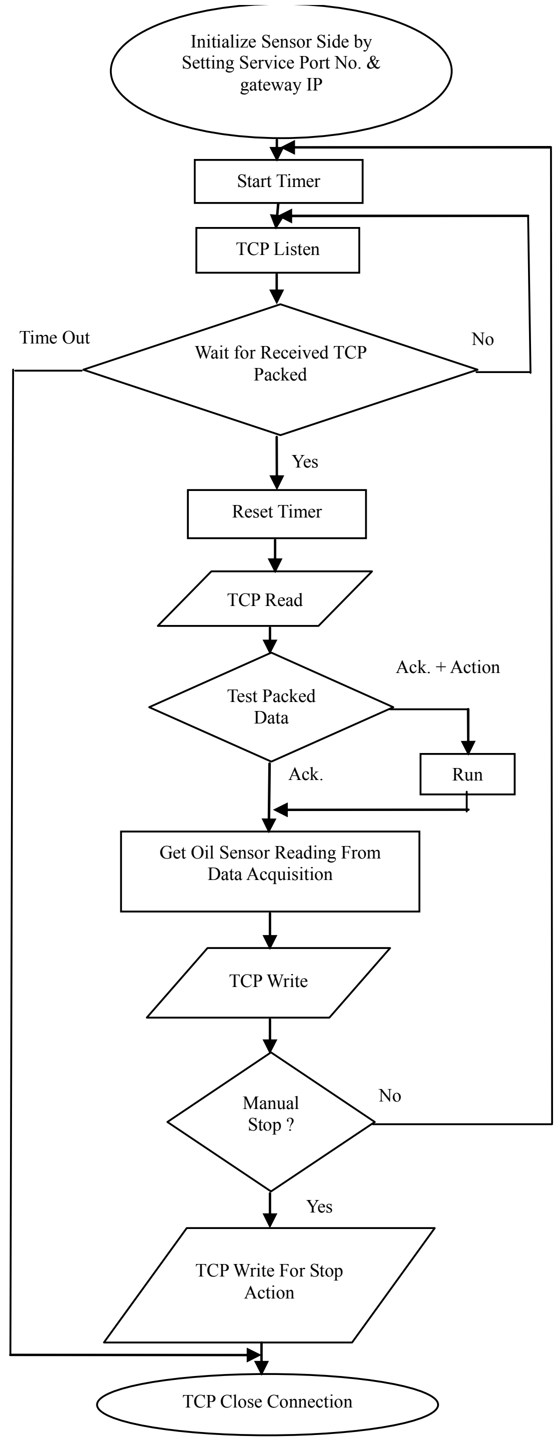


Figure 3 flow chart of Sensor side program.

6.2. Gateway Side (RTU)

The flow chart of the gateway program is shown in **Figure 5**. Also **Figure 6** shows the measurement sequence. It also starts by initialized this side by setting the port number and the IP address of the RTU. Then the program starts a timer for TCP listen block. This block search for the end nodes (in this case the wireless sensor) and obtain the values of the signals from it. Then the founded sensors by the TCP listen are connected to the RTU. After that the founded sensors send their values to the RTU. The maximum time allowed for this step is 18 seconds. However, if the RTU side did not receive the signal value within this period it will close the TCP connection.

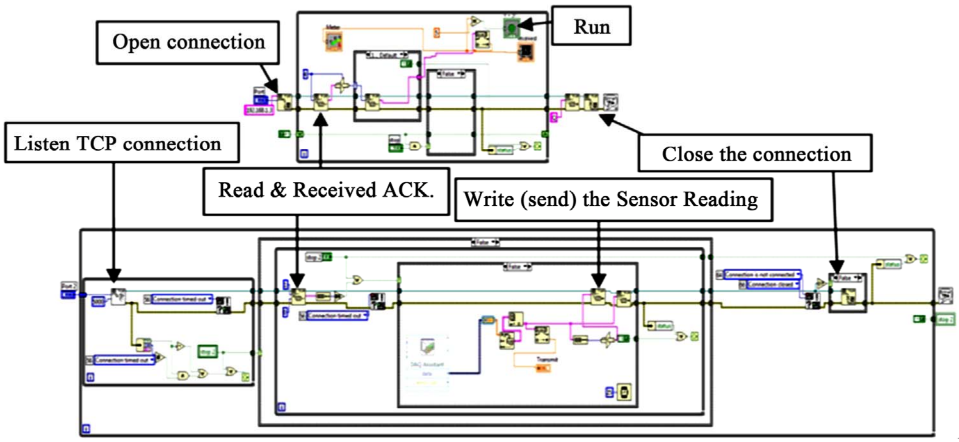


Figure 4. Lab VIEW Block diagram of the Sensor side.

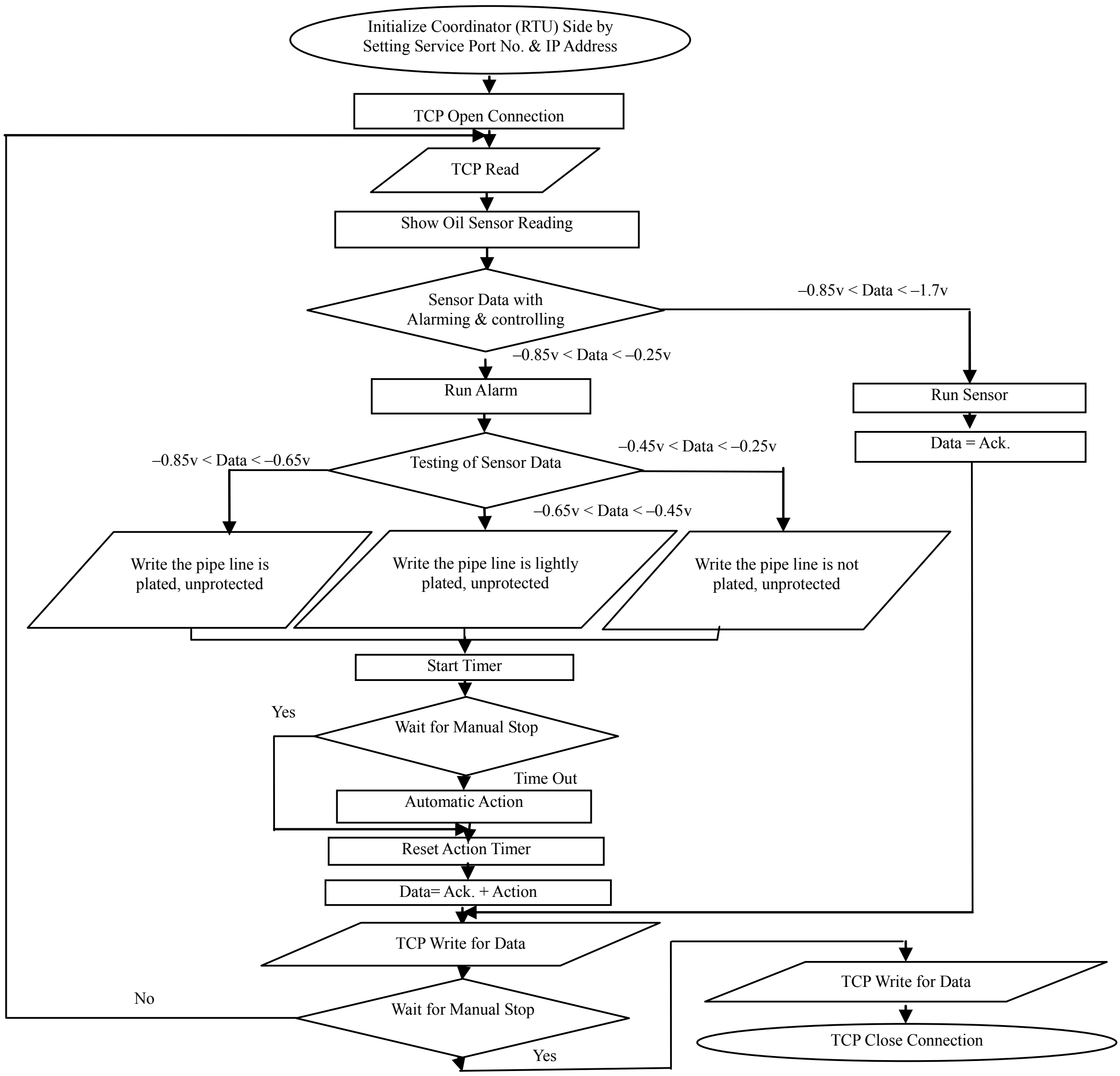


Figure 5. Flow chart of the gateway (RTU) side program.

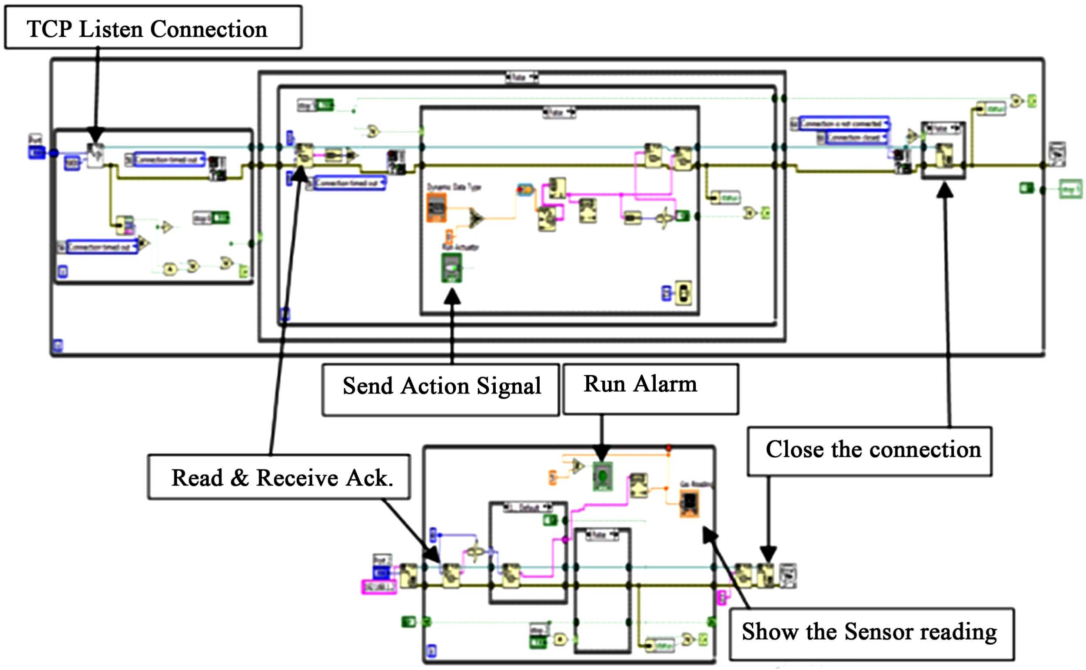


Figure 6. Block diagram of the coordinator side.

In general at the end each timer the obtained values by RTU are organized in a file and send back to the BS. The BS read the received information and the following test is made:

1) If the value obtained from the sensor is (−1.70 to −0.85) V, this means that the pipeline is plated, protected and activated as shown in **Figure 7**.

2) If the value obtained from the sensor is in the range (−0.85 to −0.25) V, this means that the pipe line is in an alarm status. Furthermore a timer is set for a specified period and a manual action must be made by the user. In addition no further readings are taken from that sensor until an action is made. The timer period is set according to the level of risk in the oil pipeline.

- If the value obtained from the sensor is in the range (−0.85 to −0.65) V, this means that the pipe line is plated, unprotected and it is in the danger of exhibition of corrosion as shown in **Figure 7.1**.
- If the value obtained from the sensor is in the range (−0.65 to −0.45) V, then the pipe line in lightly plated, unprotected (a reason for this either that the apart of the anode exhibit a corrosion or is disconnected) and it is in the danger of exhibition of corrosion as shown in **Figure 7.2**.
- If the value obtained from the sensor is in the range (−0.45 to −0.25) V, this means that the pipe line is not plated, unprotected (a reason for this either that the anode exhibit a corrosion or is disconnected) and it is in the danger of exhibition of corrosion as show **Figure 7.3**.

In **Table 2** Data from all WSNs with Update, The update of the sensor values to the base station is made every hour. **Figure 6** shows the Block diagram for the gateway side program.

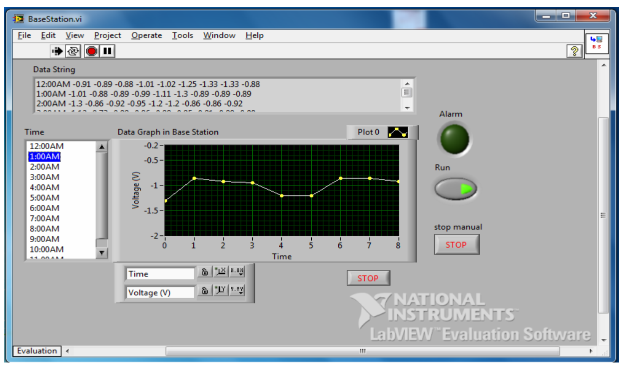


Figure 7. Normal case study in BS Front Panel.

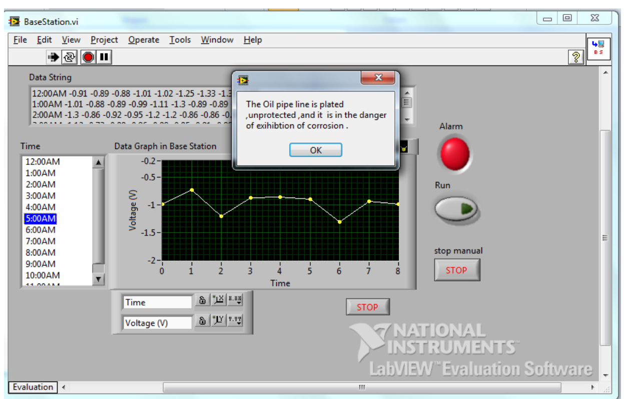


Figure 7.1. Alarm case study 1 in BS Front Panel.

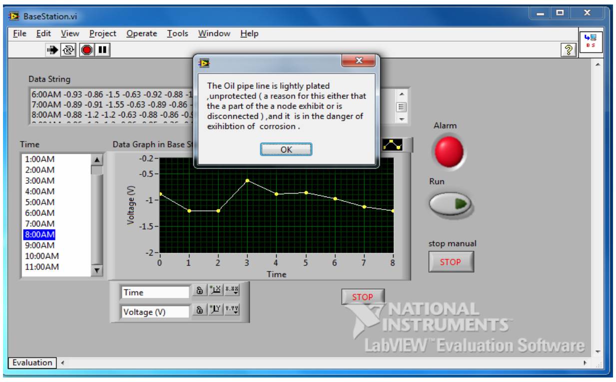


Figure 7.2. Alarm case study 2 in BS Front Panel.

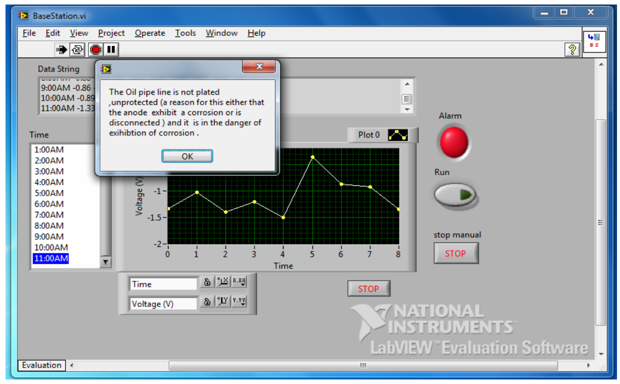


Figure 7.3. Alarm case study 3 in BS Front Panel.

Table 2. Base station data from all Wireless Sensor Network with update (Voltage in V).

Time	RTU1			RTU2			RTU3		
	WSN1	WSN2	WSN3	WSN4	WSN5	WSN6	WSN7	WSN8	WSN9
12:00AM	−0.91	−0.89	−0.88	−1.01	−1.02	−1.25	−1.33	−1.33	−0.88
1:00AM	−1.01	−0.88	−0.89	−0.99	−1.11	−1.3	−0.89	−0.89	−0.89
2:00AM	−1.3	−0.86	−0.92	−0.95	−1.2	−1.2	−0.86	−0.86	−0.92
3:00AM	−1.12	−0.73	−0.99	−0.86	−0.98	−0.95	−0.91	−0.88	−0.99
4:00AM	−0.99	−0.73	−1.3	−0.86	−0.91	−0.92	−1.01	−0.89	−0.99
5:00AM	−0.98	−0.73	−1.2	−0.87	−0.86	−0.9	−1.3	−0.93	−0.98
6:00AM	−0.93	−0.86	−1.5	−0.63	−0.92	−0.88	−1.12	−0.98	−1.35
7:00AM	−0.89	−0.91	−1.55	−0.63	−0.89	−0.86	−0.99	−0.99	−1.55
8:00AM	−0.88	−1.2	−1.2	−0.63	−0.88	−0.86	−0.97	−1.12	−1.2
9:00AM	−0.86	−1.2	−1.2	−0.86	−0.95	−0.36	−0.95	−1.3	−1.4
10:00AM	−0.89	−1.11	−1.3	−0.92	−1.2	−0.36	−0.89	−1.01	−1.3
11:00AM	−1.33	−1.02	−1.4	−1.2	−1.5	−0.36	−0.87	−0.92	−1.35

7. Conclusions

The detection system based on Cathodic protection. In this paper was enhanced detection accuracy of oil pipeline to a great extent. This system adopts multi-wireless sensor network, it has a very great superiority compare with the Voltmeter device connected directly with Oil Pipeline. It can detect the corrosion of oil pipeline precisely and reliably.

To conclude, a WSN is suggested to avoid corrosion problem in oil pipeline in state of the common CP method. In addition, a new simulation method of WSN is presented. Labview 2010 program is used as the tool to build the simulation environment. The results of a case study have been illustrated. The simulation results show that this method has least time delay, high speed, and high quality of service.

REFERENCES

[1] P. R. Roberge, “Handbook of Corrosion Engineering,” McGraw-Hill PY, New York, 2000.

[2] N. Summers, “Remote Monitoring of Pipeline Cathodic Protection Systems,” Petromin Pipeline, April-June 2009.

[3] M. Hafiz, “Modeling of Pipeline Corrosion Control by Cathodic Protection,” Ph.D. Thesis, AL-Technology University, Baghdad, 2006.

[4] S. Gundogdu and O. Sahin, “E.M.I Effects of Cathodic

Protection on Electromagnetic Flowmeters," *Sensors*, Vol. 7, No. 1, 2007, pp. 75-83.

[5] M. Al-Somaidai and O. Alsaydia, "Remote Monitoring and Controlling of Gas Sensors Using VPN Connection," *The First International Conference on Future Communication Networks ICFCN*, Baghdad, 2-5 April 2012, pp. 84-87.

[6] J. Bushman, "Corrosion and Cathodic Protection Theory," Bushman & Associates Inc., Medina, 2010.

[7] A. Kumar and L. D. Stephenson, "Comparison of Wireless Technologies for Remote Monitoring of Cathodic Protection Systems," US Army Corps of Engineers, Engineer Research and Development Center Construction Engineering Research Laboratory, Champaign, 2007.

[8] L. Ting and Z. Xiang, "Optimization Of Remote Monitoring of Cathodic Protection Power Supply System Base on Four-Tier Structure and B/S Model," *The 6th International Conference Computer Science & Education* (*ICCSE*), Singapore City, 3-5 August 2011, pp. 1346-1350.

[9] M. Parsa, S. Allahkaram and A. Ghobadi, "Simulation of Cathodic Protection Potential Distributions on Oil Well Casings," *Journal of Petroleum Science and Engineering*, Vol. 72, No. 3-4, 2010, pp. 215-219. doi:10.1016/j.petrol.2010.03.020

[10] J. Bushman, "Galvanic Anode Cathodic Protection System Design," Bushman & Associates Inc., Medina, 2010.

[11] A. Abed, "Design and Implementation of a Wireless Sensor/Actuator Network for the Development of an Industrial Wireless DCS System," Ph.D. Thesis, AL-Basra University, Basra, 2012.

[12] J. T. Al-Haidary, M. H. Hafiz and Y. M. Abdu Al-Sahib, "Galvanic Cathodic Protection Evaluation of a Steel Pipe in Iraqi Soil," *Journal of Medical Engineering & Technology*, Vol. 29, No. 9, 2011, p. 1673.

