Application of SCADA System by Using (Fuzzy Logic Controller) on the Cathodic Protection System for Oil Pipelines.

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Abstract

This study is dedicated to design and execute Supervisory Control and Data Acquisition system (SCADA) to monitor and control the corrosion of a pipeline buried under ground. A microcontroller equipped with many sensors and communication system used to control and monitor the process of an impressed current cathodic protection ICCP process for pipeline. The combination of the hardware, was built with LabVIEW and personal computer (PC) interface presents a SCADA system for two methods: Fuzzy Logic Controller (FLC) presents closed loop, and a conventional for open loop system. Hence, under temperature of 30°C, an assessment and comparison were carried out for two methods of controls examined at low moisture of soil (50%) and high moisture of soil (80 %) for measuring the potential between pipeline and anode, current, and power. It was found a decrease of (39.7%) in consumed power when the moisture of soil changing from the low to the high level. It was attained that the close loop (FLC) was the best method of performance, and consumption of the power.

Keywords: Impressed Current Cathodic Protection, (FLC), Pipeline, SCADA .

تطبيق منظومة سكادا بأستخدام المتحكم (FLC) للمراقبة و السيطرة على منظومة الحماية الكاثودية ذات التيار القسري المسلط على أنابيب النفط

الخلاصة

يتضمن البحث تصميم وتنفيذ منظومة مراقبة اشرافية وجمع المعلومات (SCADA) للمراقبة والسيطرة على تآكل انابيب النفط المصنوعة من الكاربون ستيل المدفونة تحت سطح التربة.

حيث تم تصميم منظومة ذاتية باستخدام المايكروكونترولر ومجموعة من المتحسسات لمراقبة منظومة الحماية الكاثودية التي تعمل بالتيار القصري، و استخدم برنامج اللاب فيو لبناء البرنامج الخاص بمنظومة سكادا وتم استخدام هذا البرنامج لتصميم

نوعان من المنظومات الاولى تحتوي على المسيطر (FLC) والمنظومة الثانية تحاكي المنظومة التقليدية. و تم الاختبار والمقارنة للمنظومتان في ظروف تغيير الرطوبة النسبية من (50%) الى (80%) في درجة حرارة (30°C) لدراسة تيارالانود، جهد الانود والقدرة المستهلكة للمنظومتان و تم التوصل الى ان القدرة المستهلكة للمنظومة قلت الى (39.7%) عند تغيير الرطوبة النسبية للتربة من المستوى الادنى الى الاعلى عند استخدام المسيطر (FLC) عما هو عليه في المنظومة التقليدية و ان استخذام هذا المسيطر اكثر دقة واعتمادية وسرعة استجابة وكذلك من ناحية القدرة المستهلكة للمنظومة.

1. Introduction

SCADA system is an abbreviation of supervisory control and data acquisition. A SCADA system is a type of industrial control system used to collect and control data from remote location that be considered as the backbone of modern control systems in different fields of the industry for the current century. It is employed in many control application in different branches of industry such as power plants, oil industries, transportation, water treatment plants[1]. Furthermore. SCADA systems can be used to control the corrosion in pipes, equipment's and structures through collecting data from cathodic protection system sensors in real time and display the obtained data to the observers. Also, monitoring and controlling the remote system parameters (such as current and voltage) [2].

More of engineering and economic problems come from corrosion of pipelines in oil industry. (ICCP) is an important method in industry of oil to minimize the corrosion of pipelines. Iraq has a great number of pipelines in industry of oil and transportation crude oil, natural gas and hydrocarbon products [3]. When theappropriate protection methods are used, these pipelines are exposed to damage by corrosion. Many ways were applied to minimize the corrosion of pipeline made of carbon steel such as coating, cathodic protection and painting. [4]. CP is a method applied throughout the whole world to prevent and control the electrochemical corrosion for pipelines,[2]. Corrosion happens if four elements exist: cathode, anode, metallic path and electrolyte as shown in the Figure (1).
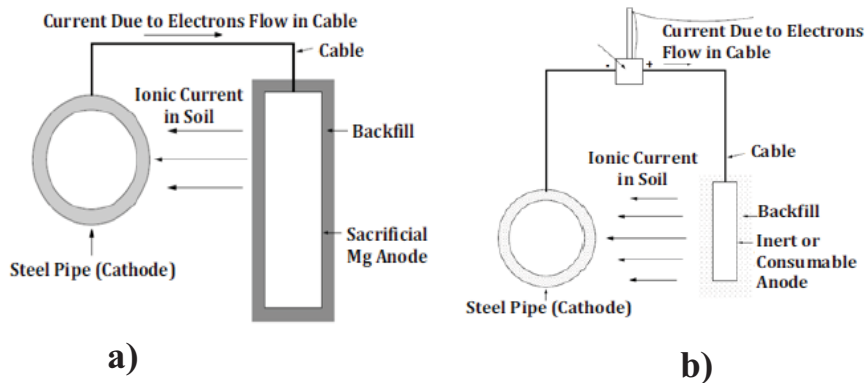
Fig. (1) a) Sacrificial or galvanic anode systems,

b) Impressed current systems [5]

CP achieved by the two techniques [2]:

1) Sacrificial anode : by forming an electrochemical circuit to achieve electrical connection between the structures (cathode) to a sacrificial metal that have more negative potential acts as the anode. The sacrificial anode such as zinc or magnesium is consumed and must eventually be replaced as shown in the Figure (1) (a).

2) ICCP: this technique based on an impress current employs between a cathode and anode, as shown in the Figure (1) (b) [6].

For the time being, the industrial systems include (SCADA) systems that are used for controlling and monitoring operations. A SCADA consists of a number of sensors as remote terminal units (RTUs) collecting the data and transmit it to a central unit through a communications media system. The central controlling unit monitors the obtained data and allows the operator to execute different remote control function [1]. As shown in the Figure (2).

The research devoted design and implementation SCADA system for (ICCP) system and study the main parameter effected (humidity changes) then measure anode current, anode voltage, power for both the tradition and controlled (ICCP) system.
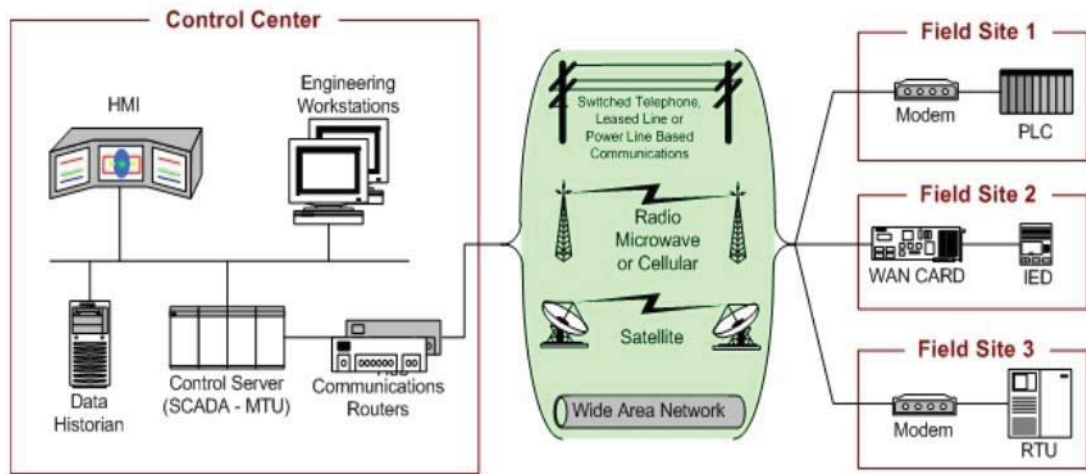
Fig. (2) SCADA system general layout [1].

Cathodic protection has been studied by many researches for the different processes. **[7]** Studied the performance of ICCP cathodic protection for pipeline of 100 cm length buried in soil. Several important factors affecting the pipeline protection against corrosion has been studied such as position of anode (depth and distance), resistivity of soil (dry and wet), the used pipeline (un-coated, coated) and the amount of required current to achieve protection system. **[8]** Studied using the SCADA system and using Service Oriented Architecture (SOA) techniques for monitoring and control the crude transportation and refined petroleum products via oil pipelines systems. This technique based on reduces network traffic, supplies the ability of operator to participate in the pipeline processes system. [**9**] applied two type of ICCP controls; PID and intelligent (Fuzzy and neural) to reduce the corrosion of oil pipelines to a desired potential level measured by copper copper sulfate reference electrode (CCSRE) cell. In addition to the experimrntal work, a simulation work was done using Matlab^{TM} software which simulates the experimental field of carbon steel pipelines. The study was devoted on increasing the value of protection current through increasing the solution conductivity through changing the NACL concentration and areation flow rates.

 [10] Achieved a transformer rectifier unit and algorithm based on (FLC) for cathodic protection system implementation using modern microcontroller (PIC16F877). This allows a large flexibility for variation real time applications. The protection voltage is adjusted by keyboard and the output values are showed on a liquid crystal display screen. The system based on (FLC) was implemented to measure for the variations changes of the environment conditions.

This study is concerned to design of a SCADA system for ICCP system to control and monitor. This CP system was built in two methods namely; the conventional system (open loop method) and (FLC) that support closed loop system. The control process was designed by controlling the applied voltage for anode to keep the protection voltage within the protection limits.

The inputs in open loop systems are applied to drive the outputs with unknown value of the output of system through feedback signal as shown in the Figure (3).
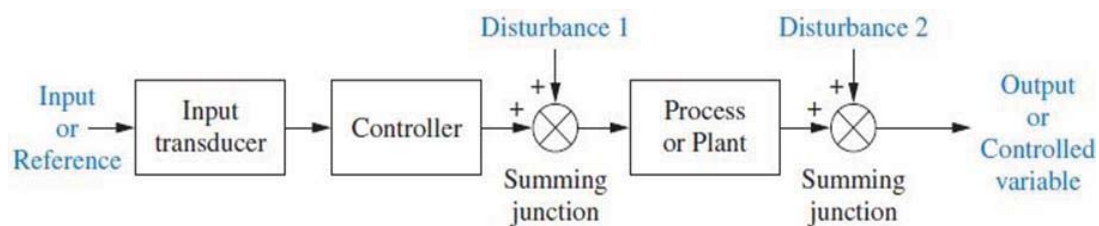

Fig. (3) Open loop System [11]

Thus, this method of control is not effective and is mostly influenced by the disturbances [12]. The closed loop system developed to use the concept of open loop with addition of one or more feedback between the output and the input. (FLC) is a closed loop control strategy as shown in the Figure (4). A (FLC) adjusts the output signal at a low difference between the process variable y (t) and the reference input r (t) [13].
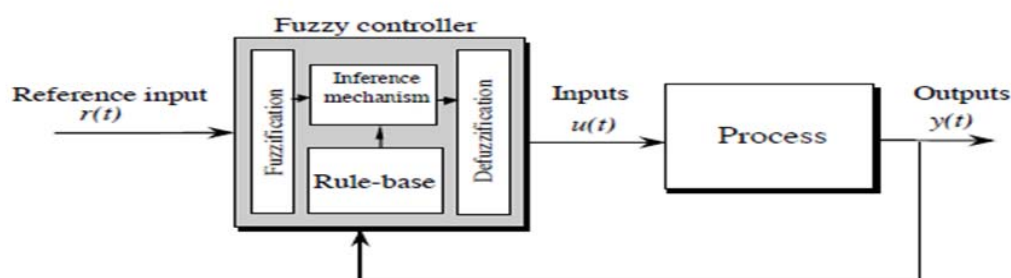

Fig. (4) FLC Block Diagram [14]

FLC is a closed loop control system that based on a mathematical input values in terms of logical variables that take the values between 0 and 1. That used by expert systems in process control. It uses to control processes symbolized by subjective, linguistic variable input, output and descriptions boundaries of fuzzy sets. It is an active choice when precise is necessary. A (FLC) use known rules to control the fuzzy process system that based on the present of input

variables value and output variables as shown in the Figure (5) [14]. The multi inputs is the error (difference between the desired value and the process variable the output value of system) and the rate change of error (difference between the error and the new error).
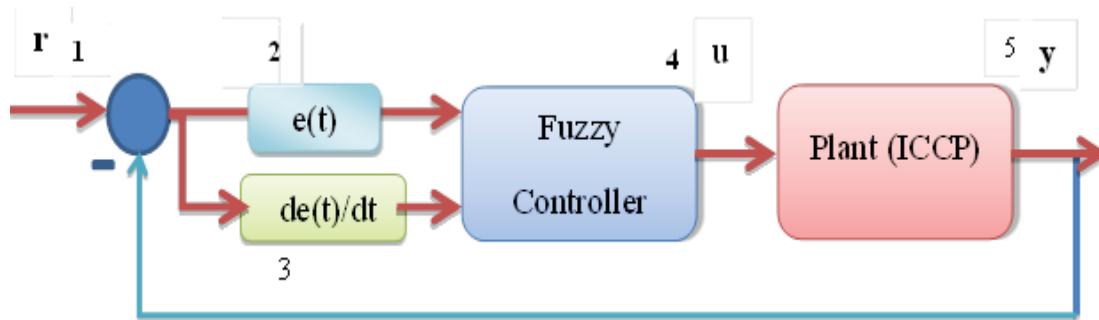

Fig. (5) Fuzzy Controller Block Diagram System: 1. set point, 2. e (t): error, 3. de (t)/dt: error change, 4. u: FLC of output, 5. y: output of control

2. Materials and Experimental work

2.1 Materials

A pipeline is made of carbon steel of (0.27) m length, (0.115) m outside diameter and 0.01m wall thickness was used in this investigation. As shown in the Figure 6. A sample of the pipeline material is analyzed in the Ministry of Science and Technology Corrosion Department laboratory; the analysis result shows that the chemical composition as illustrated in Table (1).

Fig. (6) Uncoated carbon steel pipe.

Table (1) The composition of the pipeline.

C%	Si%	Mn%	S%	P%	Cr%	Ni%	Cu%	V%	Fe%	Others
0.25	0.6	1.65	0.03	0.03	0.3	0.3	0.5	0.06	95.21	1.07

A piece of iron (low carbon steel) of (0.3) m length, (0.035) m width (0.002) m thickness and (0.02) m height used as anode as shown in Figure (7).

Fig. (7) Anode.

2.2 Experimental work

A suitable Copper wire brazed to the outside surface of pipeline as (cathode) to achieve negative electrical voltage for system as shown in Figure (6) [14]. Then the pipeline segment is horizontally installed inside a box made of wood filled with suitable soil at 0.5 m depth as the cathode, a suitable copper wire connected to the iron segment (anode) to achieve the positive voltage to the system. The anode was installed in the opposite and horizontally to the pipeline at the same level. An electronic and electrical components were assembly to build the smart ICCP system as shown in Figure (8).

Fig. (8) Components of System.

The (FLC) block diagram is simply shown in Figure (9) .A (copper copper sulfate reference electrode- CCSRE) is used to measure the potential difference between the carbon steel pipeline (cathode) and the environment soil [50].
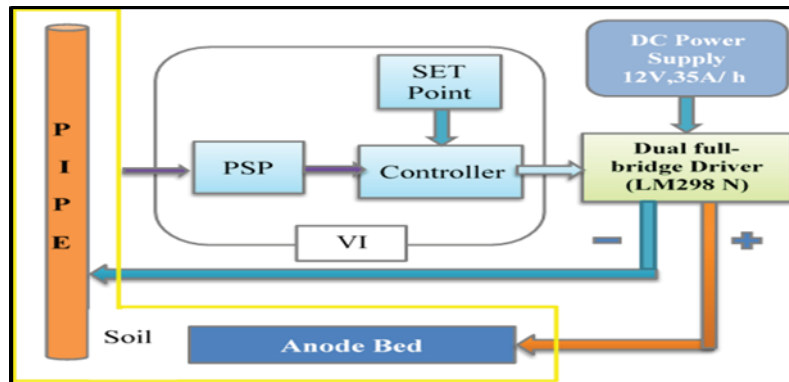
Fig. (9) The block diagram of system.

Figure (10) a, shows the (CCSRE) and the connection diagram with Arduino. The microcontroller board, which is considered as (RTU), is based on the Arduino platform. Ii is an essential device for making the necessary control to the applied anode voltage to minimize the error and keep the protection voltage (PSP) at range (-0.85 V to -1.125 V). The microcontroller Arduino drives voltage by the driver type Lm298N as shown in the Figure (10) b, to supply the necessary (0-12) V anode voltage. A number of electronic sensors were installed to measure and feed the microcontroller board the important ICCP system parameters such as current, anode voltage, soil humidity, and environment temperature.
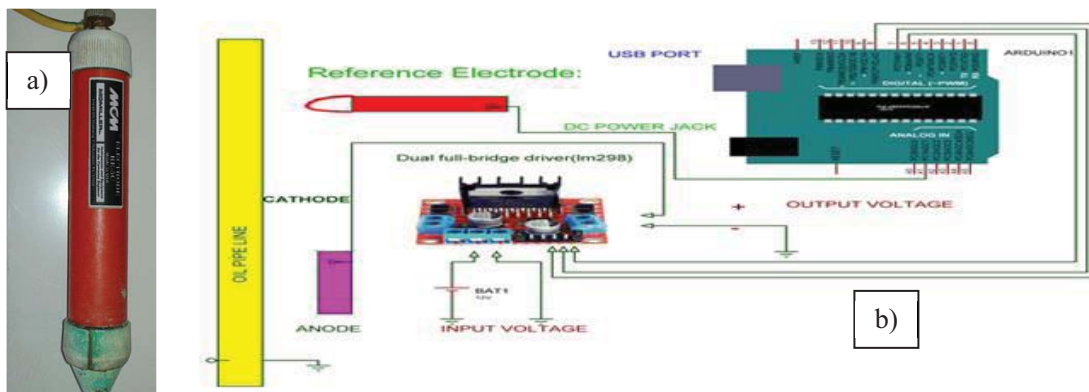

Fig. (10) a) Reference electrode, b) Connection diagram of reference electrode to Arduino.

2.3 Smart Design for ICCP System.

The ICCP system was turned on in two methods: the conventional method and (FLC) closed loop method. The first one is monitored and controlled manually and the second one is a smart system in control and monitor operations. The LabVIEW Software used to design platform of systems.
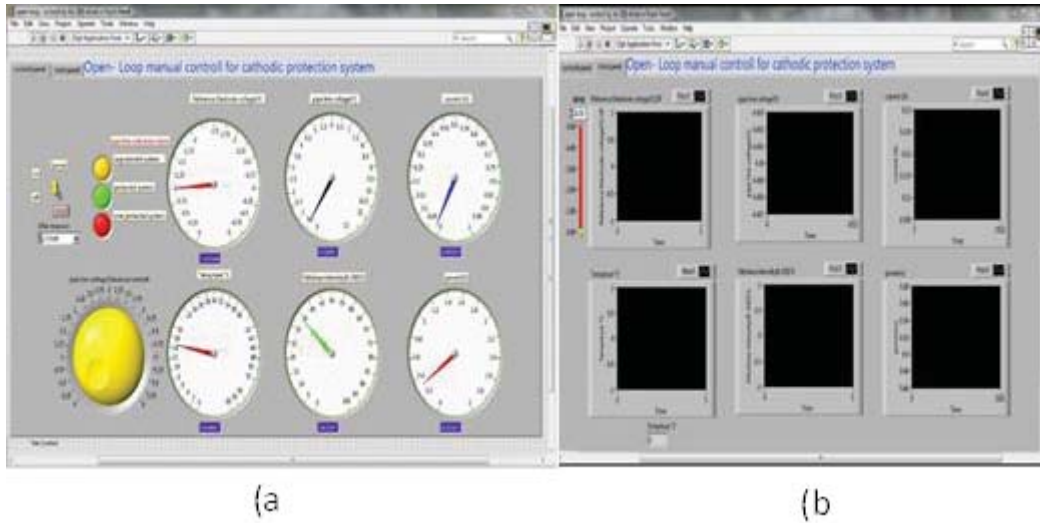
Fig. (11) HMI design by LabVIEW for the conventional system; (a) main panel and (b) measured parameters with Time.

It is supported by National Instruments, and used to design and implement the experimental work of the systems for both methods as shown in Figure (11). Shows the design of HMI for the conventional system where data manual controlling processes and visually monitoring.

Figure (12) a, b, c shows the Lab VIEW design HMI of SCADA system using (FLC) real time controller for the ICCP smart system.
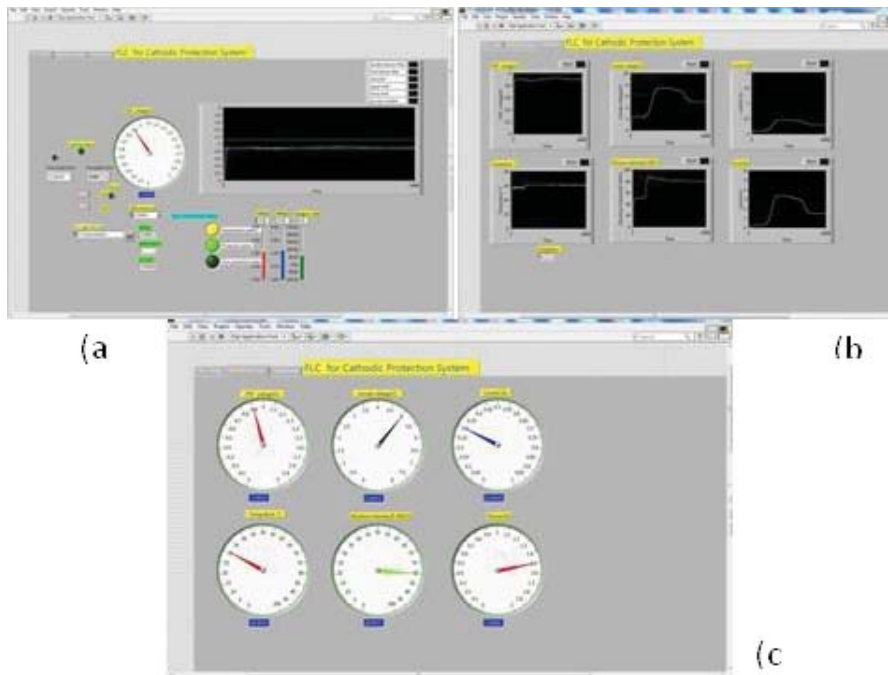

Fig. (12) HMI design by Lab VIEW for (FLC); (a) main panel, (b) Measured Parameters with time and (c) meters.

During the front panel, the worker manually controls the applied voltage of anode and measures the current flow, protection potential, anode voltage, power, temperature and moisture of soil.

3. Results and analysis

The strategy of research is based on applying an ICCP process on pipeline with two control methods, the conventional and automatic system to achieve the protected pipeline within the lower and upper protection limits. If the protection voltage PSP changes under the lower protection limit the oxidation occurs. so, when the PSP raised up the upper limit, the surface of coating for pipeline will suffer from degradation.

The aim is to obtain the optimum measured parameters and test the performance of ICCP system and effectiveness of both methods. The results of two methodes are taken at temperature environment (30°C) and two soil moisture levels: the medium level of 50% and the high level of 80%.

3.1 Conventional Open Loop Results

In this method, the protection potential PSP reach to (-0.9 V) for both moisture of soil levels requires 50 s which is too small. As shown in Figure (13). The protection potential area is between (-0.85 V and -1.125 V). The measured parameters by the LabVIEW display the voltage of anode and the current steady at 3.18 V and 0.155 A for the medium level, and 7.7 V and 0.49 A for the high level as shown in Figure (14). That shows a gradually increase in the power from "0.494 W to 3.77 W" when the moisture of soil changes from medium to high level. The clear difference between the results for two tests, medium and high, is concerning soil resistance changing due to moisture of soil variations. Increasing the amount of the water in the soil increases the moisture and decreases the electrical resistance of soil. Depending on Ohm's law (V=R*I) when the resistance of soil between cathode and anode decreases, the current would be increased. So, the anode voltage would be manually increased to reach to protection potential PSP. This shows that the voltage, current and power consumption increasing in conventional ICCP system.
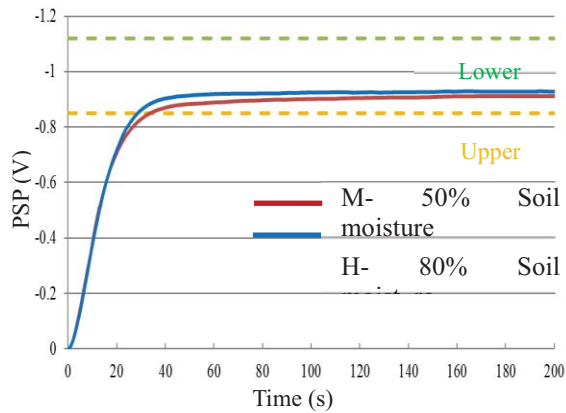
Fig. (13) Pipe to soil potential for medium (M) and high moisture (H) of soil levels for conventional system
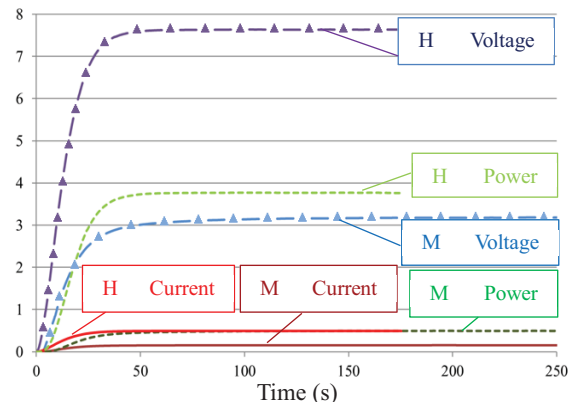

Fig. (14) Measured parameter of the current, anode voltage and consumed power for conventional control system at (medium-M and high-H- levels) of moisture of soil.

3.2 The Smart (FLC) Closed Loop Results

The (FLC) provides the ICCP system with the desired anode voltage to make the system protection voltage within a required protection limits (-0.85 V to -0.125 V). The first test was done at the medium level of soil moisture and the second test was done when the moisture of soil changes from medium level of 50% to the high level of 80% during the operation. Moreover, the (FLC) system was tested for a more time. The effective measurement of the protection voltage PSP is done with electronic sensor and noises of environmental. Thus, Kalman filter were used to minimize the noise of measured parameters as shown in the Figure (15).
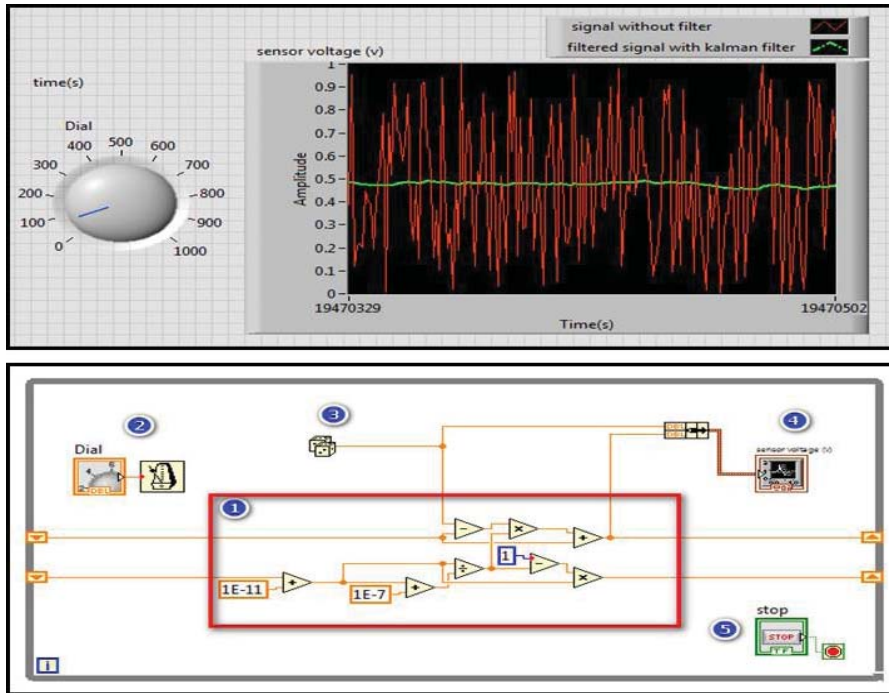
Fig. (15) Kalman filter signal graph and design by Lab VIEW [15].

Figure (16) shows the value of protection voltage as a function of time. The (FLC) keeps the PSP potential constant along the operation of process within the ICCP protection limits. The feedback of measurement signals without using filter contain errors that clear in shape of ripples as shown in the magnified area in the Figure (16). So using suitable filter to minimize the undesired components. The purpose of using Kalman filter is to remove the noise from data and provide accurate measurements for the ICCP system parameters. Hence, using Kalman filter in the ICCP system taking more time than the no filter case.
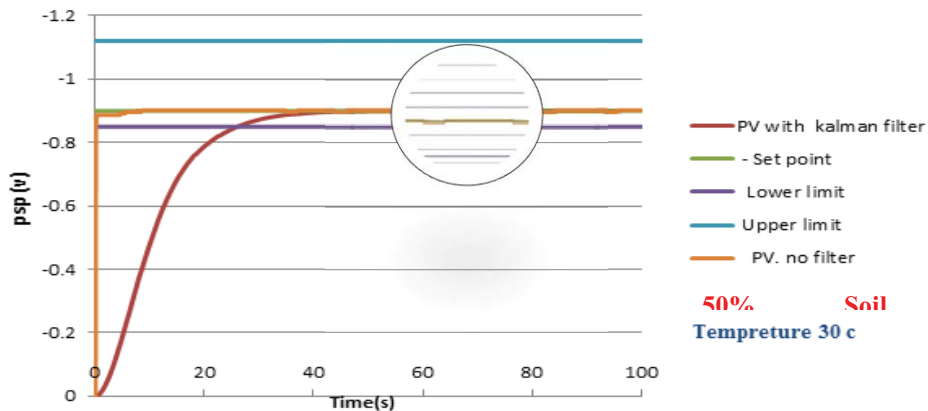

Fig. (16) PSP Value for Closed Loop

The purpose of (FLC) to keep the PSP in range of the protection limits (-0.85 V to -0.125 V). When the moisture of soil changed from the medium level (50%) to high level (80%) after an amount of water adding along the pipeline as shown in the magnified area of Figure (17) a, b. The (FLC) monitors the output signal and compares it with the desired set point value. The signal of feedback form PSP sensor is analyzing by the rules of (FLC).
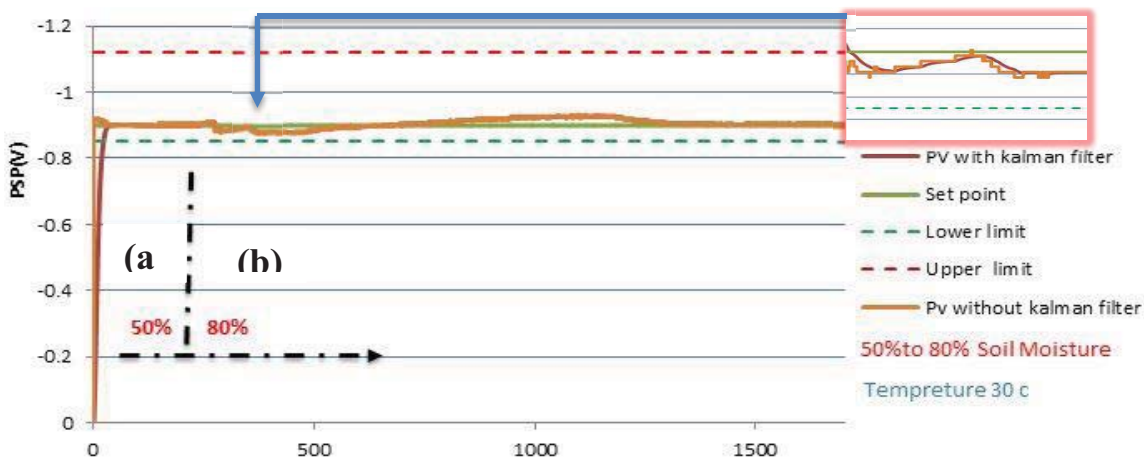

Fig. (17) Closed loop control for medium and high moisture of soil levels.

The signal of returned feedback sensor PSP is computed by the (FLC). Error is the difference between desired value and measured value is applied with (error change) as feedback to the input of (FLC) to make the output near to the set point desired value) of (-0.9 V). An effectiveness of the smart system to keep the protected potential PSP at the specified protection limits at -0.9 V. The accuracy of the smart system to preserve the PSP value at (-0.9 V) under changing moisture of soil. So, the important advantage is a fast system response time (40 s) of the FLC, as shown in the Figure (17), the desired value was adjusted at the -0.9 V value for the protection voltage PSP. During using Kalman filter, the undesired components were canceled, in the smart ICCP system.

Figure (18) displays that the measured parameters for the smart ICCP system when soil moisture change from medium to high levels. The anode voltage increased at the onset of protection limits then remains at (2.57 V and 5.01 V) for changing the soil moisture from medium and high level respectively. The current and the power are (0.123 A and 0.31 W) for the medium soil level. Likewise, for the high soil level the current and power stable at (0. 302 A and 1.5 W).
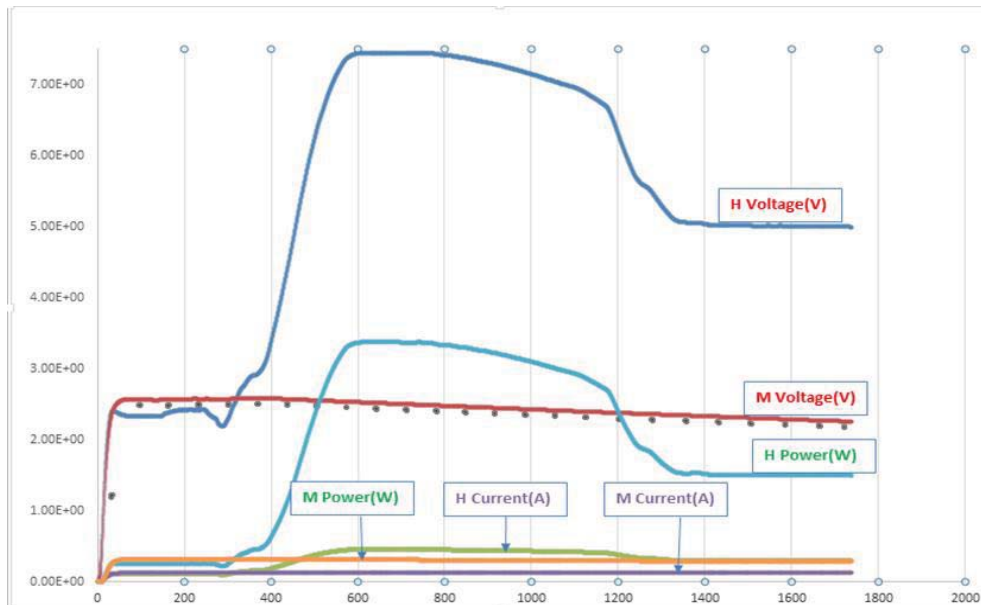
Fig. (18) (FLC) for the anode voltage, current and power for the levels (medium and high) moisture of soil.

4. Conclusions

The concluding remarks are drawn from the experimental and computational investigations.

1. The closed loop controller is more stable and higher efficiency for the ICCP system. Where, no rust formation was observed through the FLC.

2. Open loop system must be continuous monitoring and manual control according to the value of PSP visually observed.

3. Kalman filter is important filter to minimize the noise of PSP signal and improve the process of control.

4. The measured parameters: anode voltage, current and consumed power is increasing with increase the moisture of soil for both the conventional and the intelligent systems.

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