Evolution in Electrical and Electronic Engineering Vol. 3 No. 2 (2022) 258-266

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Development of an Arduino Based Electrical Instrumentation Unit for a Remote Monitoring Cathodic Protection System

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DOI: https://doi.org/10.30880/eeee.2022.03.02.030
Received 27 August 2022; Accepted 12 September 2022; Available online 30 October 2022

Abstract: Underground pipelines are one of the most important infrastructures in the world for transporting liquid or gas. These pipelines are protected against corrosion through a cathodic protection (CP) system which the system was designed to achieve the required electrical current flow in to protect the steel pipeline from corrosion. One major challenge in the pipeline operation is the measurement of the cathodic protection parameters needs a lot of time to travel and money due to the remotely located test post. Therefore, the monitoring system needs to be improved so it can provide minimal time to monitor the CP system and decreasing in term of operational costs. The developed monitoring unit is equipped with a sensor (ADS1115) as a voltage sensor for CP parameter measurement. The findings indicate that the device was capable to measure potential readings as precisely as a conventional multimeter after the experiment setup was conducted. Based on the data collection using Arduino based measurement unit, the potential readings for corrosion free is higher than corroded steel and the observation is conducted to study the behavior of steel in terms of cathodic protection. In addition, this unit will provide detailed information about analyzing potential differences without voltage divider error by using floating points and the measuring system for the CP system.

Keywords: Electrical Measurement Unit, Arduino, Voltage Sensor, Cathodic Protection, Corrosion

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1. Introduction

Corrosion is the primary mechanism through which metallic materials deteriorate. As a result, corrosion prevention through metallic structure protection is critical for structural safety, integrity, and function long service life. Corrosion mostly is happened in a cathodic area that is applied for Cathodic protection. Cathodic protection (CP) is a method of reducing the rate of metal corrosion by maintaining the metal electrochemical potential at levels that prevent corrosion [1]. Cathodic protection is mostly implemented in numerous industries which is want to protect a broad range of structures in challenging and aggressive environments such as the oil and gas industry [2]. The goal of this technology is to prevent energy leakage by providing current to the structure's surface. Because Malaysia is a country rich in natural resources as well as a fully developed country, the use of underground pipelines for transferring energy products such as petroleum and natural gas is critical [3].

Then, Cathodic protection (CP) comes with two methods to solve the energy leakage that happened in the pipeline is passive cathodic protection and impressed current cathodic protection. The sacrificial anode is connected directly or indirectly to the metal to be protected in passive cathodic protection systems. The difference in potential between the two dissimilar metals generates enough electricity to form an electrochemical cell and drive galvanic or bimetallic corrosion. Impressed current cathodic protection (ICCP) is when an external power source is used to help drive the electrochemical reactions in long structures, such as underground pipelines, which benefit greatly from ICCP systems [2]. In this work, the ICCP method is used for potential measurement using Arduino based measurement.

2. Materials and Methods

The proposed work consists of several stages of development.

2.1 Software Development

i. The development of the project is based on Proteus 8 Professional which to analyze the potential measurement without voltage divider error.

The interpretation of a buried ICCP system as an Equivalent circuit is visualized in Figure 1.

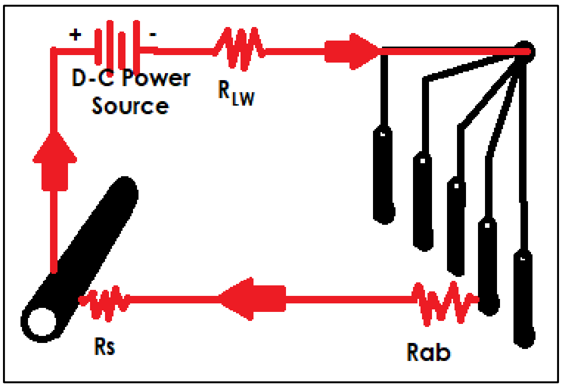

Figure 1: Equivalent circuit for impressed current

To find the allowable anode bed resistance is by using this formula:

$$R_{ab} = R_{max} - (R_s + R_{LW}) \quad \text{(Eqn. 1)}$$

where

R_{ab} is allowable anode bed resistance, R_s is maximum allowable circuit resistance, and R_{LW} is total lead wire resistance

To find the maximum allowable circuit resistance is by using this formula:

$$R_{max} = 70\% \left(\frac{E_d}{I} \right), \quad \text{(Eqn. 2)}$$

where

E_d is the driving potential of the galvanic anode, and I is the current requirement of the structure

To find the formula of structure to electrolyte resistance is by using the formula:

$$R_S = \frac{(V_{on} - V_{off})}{I_{on}}, \quad \text{(Eqn. 3)}$$

where

V_{on} is structure potential with current on, V_{off} is structure potential with current off and I_{on} is currently applied to make a shift.

Based on all equations, it is stated to get the parameter to substitute in the circuit simulation. The value of the parameter is shown in Table 1.

Table 1: Values of parameters for ICCP method

Impressed Current	
Parameter	Value
Length	2 [m]
Diameter	91.4 [cm]
Structure-to-electrolyte resistance, R_S	0.81 [Ω]
Lead wire resistance 1, $R_{LW}1$	0.014 [Ω]
Lead wire resistance 2, $R_{LW}2$	0.005 [Ω]
Total lead wire resistance, R_{LW}	0.019 [Ω]
Maximum allowable circuit resistance, R_{max}	0.96 [Ω]
Allowable anode bed resistance, R_{ab}	0.13 [Ω]

Based on Table 1, the parameters will be used in circuit simulation to get the potential difference between R_S and R_{ab} . Figure 2 shows the simulation circuit for method impressed current.

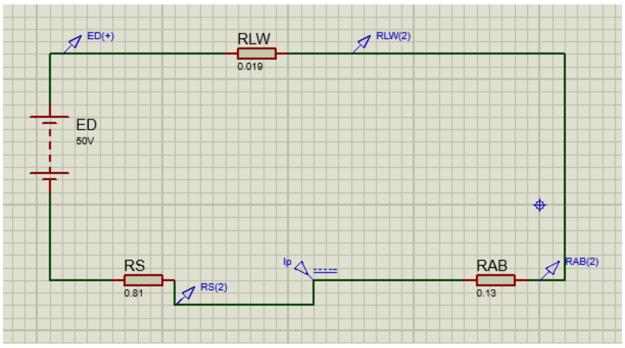

Figure 2: Simulation for method impressed current (ICCP)

ii. The circuit simulation be designed using Proteus 8 Professional while coding using Arduino IDE. The circuit simulation is designed on measuring the potential difference by using Arduino UNO. Figure 3.2 is showing the whole circuit of the CP system. The components that be included are Arduino Uno, a Virtual terminal and simulated voltage sensor. Arduino Uno is acts as microcontroller which control the system and a dummy of potentiometer to collect data for voltage measurement. Figure 3 is the circuit simulation of CP system Device.

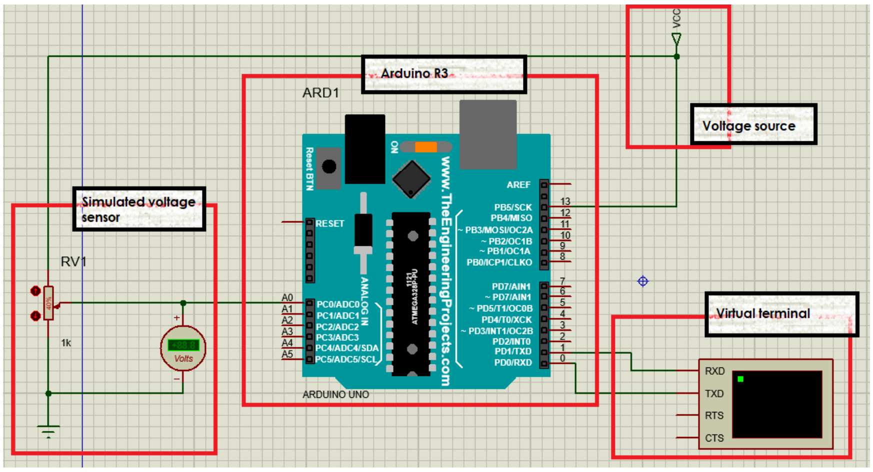

Figure 3: Circuit simulation of CP system Device

2.2 Hardware Development

Figure 4 shows the complete hardware for the CP system. This circuit system will be test on cathodic area testing. When the USB cable be connected to Arduino UNO to power bank, it will in "ON" mode and the measurement can be occur. Then I2C LCD Display will be appear reading of voltage.

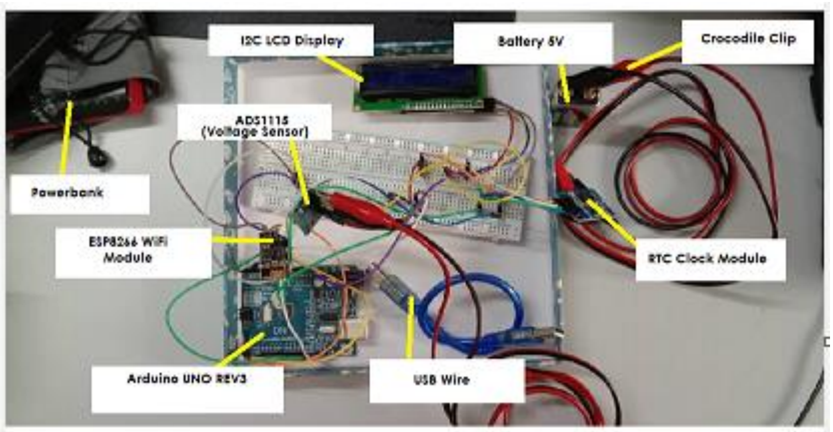

Figure 4: Complete hardware for CP system

2.3 Experiment Setup

Figure 5 shows the experimental setup for the first case study. The first case study is to observe the potential difference or voltage between the Reference electrode (RE) and the corrosion-free steel which is the cathode. To see clearer with this setup without measurement is in Figure 6. For this setup, had 2 cases that are potentially different with RE and corrosion-free steel and another one is potentially different with RE and the corrosion occurs on steel. The second setup is on Figure 7. From Figure 5 until Figure 7, the red wire from voltage is act as negative terminal while the black wire is positive terminal.

Figure 5: Experimental setup for first case

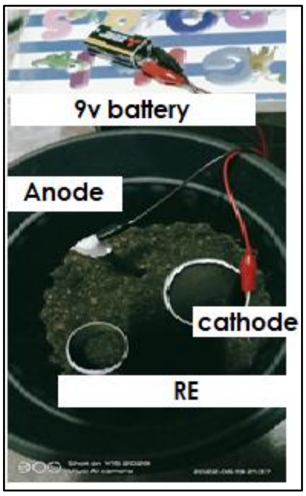

Figure 6: Experimental setup for first case without measurement circuit

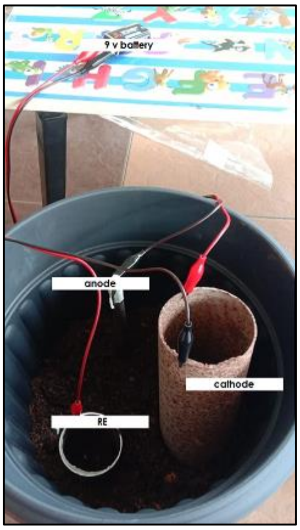

Figure 7: Experimental setup for the second case

3. Results and Discussion

The result and discussion will be contained about the analysis of measuring the potential difference between floating points, measuring the potential difference using remote electrical measurement and verifying the measurement of based Arduino UNO.

3.1 Simulation using Proteus 8 Professional

Simulation results for an impressed current method are summarized in Table 2. The table showed the comparison between simulation and calculation. Figure 8 shows a simulation circuit run in the simulation tool.

Table 2: Output voltage from circuit simulation and calculation

Calculation method	Impressed current system Simulation method	Percentage error
Voltage drop is	Voltage drop are	
$V_{LW} = V_S = V_{AB} =$ $V_{bat} = 24.9975$ V	$V_{out(S)} = 24.70V$	$\%error_{Vs} = 1.19\%$
	$V_{out(AB)} = 6.77V$	$\%error_{Vs} = 72.92\%$

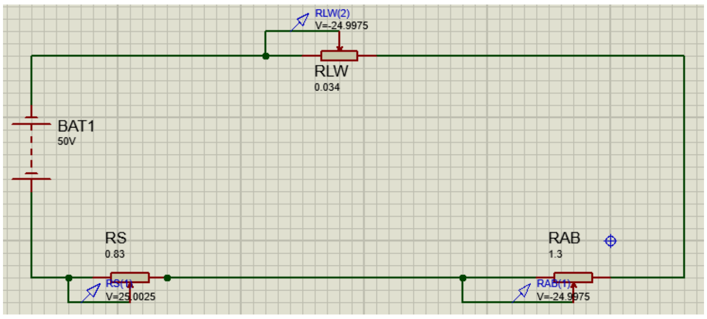

Figure 8: Result for impressed current (ICCP)

When comparing the value of manual calculation and simulation for both methods, it showed that the ICCP method can monitor the high value of the corrosion if occur in the pipeline. It is because the value of potential difference at sacrificial is much lesser that the ICCP. If using the sacrificial anode method has the highest value of the plate anode or pipeline, the method of sacrificial cannot analyze it. Besides it also, the percentage error for impressed current is much lower than the sacrificial error which for $V_{out(S)}$. Then, it is proven that the impressed current is the best choice for this monitoring system in cathodic protection.

3.2 Potential Measurement Based on Arduino

3.2.1 Potential Measurement between Corrosion Free Steel to Reference Pipe

Table 3 compares measurements taken by hand with a multimeter to measurements taken by a device. The measurement was made in 15 seconds. Figure 9 depicts a comparison of multimeter and CP System Device measurements. Figure 10 depicts a potential measurement graph using Excel.

Table 3: Comparing measurement betweem multimeter and device measurement

Multimeter Measurement (mV)	Device Measurement (mV)	Accuracy (%)
0567	0564	99.995
0586	0580	99.990
0640	0635	99.992
0750	0740	99.986
0789	0764	99.967

Figure 9: Comparison of multimeter and CP System Device measurements

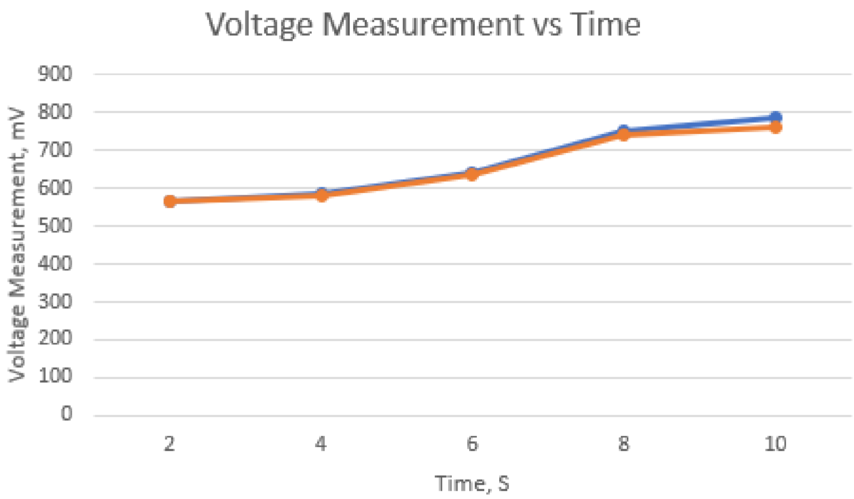

Figure 10: Graph voltage vs time

3.2.2 Potential Measurement between Corroded Steel to Reference Pipe

Table 4 compares measurements taken by hand with a multimeter to measurements taken by a device. The measurement was made in 15 seconds. Figure 11 depicts a comparison of multimeter and CP System Device measurements. Figure 12 depicts a potential measurement graph using Excel.

Table 4: Comparing measurement within multimeter and device measurement

Multimeter Measurement (mV)	Device Measurement (mV)	Accuracy (%)
2390	2417	98.870
2420	2414	99.998
2470	2455	99.994
2589	2584	99.998
2591	2583	99.997

Figure 11: Comparison of multimeter and CP System Device measurements

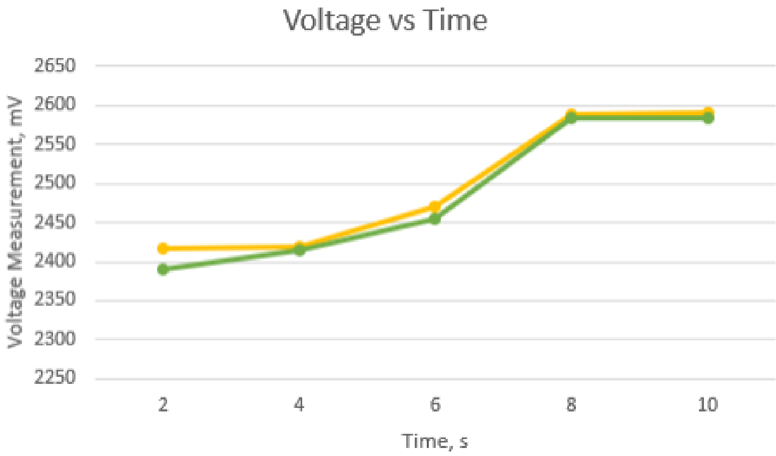

Figure 12: Graph voltage vs time using Excel

Then proceed with Table 5 showed the parameter measurement for Arduino based potential measurement. This parameter being observe to verify the measurement of remote electrical was valid for this measurement due to the new method by using Arduino UNO.

Table 5: Parameter measurement based on Arduino UNO

Parameter measurement	Multimeter measurement	Device measurement
Resolution	0.01V (voltage range =20V)	0.0125mv (voltage rage = ±4.096V)
Precision	Not Precise	Precise
Sensitivity	$1 \pm 0.01V$	$1 \pm 0.0125V$
Accuracy	$\pm 0.5\%$	± 0.043421905

3.3 Discussion

Based on Table 2 that showed comparing measurement within multimeter and device measurement, the value that is got in the first case study had high accuracy between value voltage for device and multimeter. It also got a similar result for the second case study based on Table 3. Based on Table 4, in terms of the accuracy for a device or by using Arduino UNO is much more closely due to more significant bits while using a multimeter is too small and less significant bits. Next, the precision for the multimeter is lower than the device using Arduino UNO. It is because the value for the device is mostly close to each other. In terms of sensitivity, the device measurement is much had high sensitivity that the multimeter. It is due to the set for the multimeter already being stated on 20V, the sensitivity is $\pm 0.01V$ but for Arduino UNO, it is easier because the value of the setting can be chosen regarding the range value that is decided. Lastly, about the resolution, it contributes from the sensitivity part, in which the device also got high in a significant bit rather than a multimeter. By this method observation, the based method measurement using the Arduino UNO was verified by this parameter in Table 3.

The voltage for corroded steel is substantially higher than the voltage for corrosion-free steel, based on the potential measurements. Corrosion-free steel uses more electricity than rusted steel. When the current rises, the voltage falls. Because of the tiny quantity of current consumed, the voltage of corroded steel is substantially higher. Based on Table 3 and Table 4, the voltage value could be seen to become greater when changing to the rusted pipe. By that, it was be seen as the successful design of electrical measurement using Arduino UNO and the ADS1115. By comparing on Table 5, it showed the capability of the device quite close to a multimeter and it is a sign that the device could be a better version of a multimeter.

4. Conclusion

The objectives are successfully achieved in this project. A concept of potential measurement without voltage divider error is achieved by doing manual and simulation calculations specific to the ICCP method. A high impedance DC potential measurement was able to measure by using a voltage sensor which is ADS1115 and also Arduino UNO REV3. This concept is approved by measurement values by voltage sensor of the developed system are comparable to a conventional digital multimeter with an accuracy of 99%. Based on data that be recorded, it is verified again based on Arduino UNO potential measurement with a conventional multimeter. The outcomes are the Arduino UNO potential measurement is the suitable and better due to high of sensitivity, precision, resolution and accuracy.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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