# An Online-Enabled Remote Monitoring Device for Assessing Polarization and Depolarization Potential Behavior of Cathodic Protection Systems in Underground Pipelines

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*Abstract*—**Metallic structures, such as pipelines and storage tanks, are among the most critical infrastructures worldwide for transporting liquids or gases. Conventional on-site inspections and monitoring methods are not effective in detecting sudden or occasional failures due to corrosion in these metallic structures. Therefore, a continuous monitoring system is necessary to provide early warnings for immediate mitigation and to monitor the cathodic protection (CP) operating conditions and its surrounding environments. A test post remote monitoring system, equipped with voltage, humidity, and battery capacity sensors is developed and integrated with an industrial internet of things (IIoT) platform. Node-RED was utilized to develop an interface for monitoring parameters collected from the system via a communication protocol. The findings indicate that the remote monitoring system can measure potential readings with a low error of within 1% comparable to a conventional multimeter. Furthermore, the system enables monitoring the polarization and depolarization potential behavior during cathodic protection operation conditions on a pipeline.**

*Keywords— remote monitoring, IIoT, cathodic protection, sensor, potential measurement, polarization and depolarization potential*

## I. INTRODUCTION

Metallic structures such as pipelines, steel storage tanks, and steel platforms have been the preferred means of transportation and distribution for various liquid and gas utilities such as oil, gas, chemicals, water, steam, petroleum products, and other substances [1,2]. However, these critical assets are severely threatened by corrosion, as the cost of mitigating corrosion is extremely expensive. Corrosion occurs naturally on the deterioration of material or its properties due to reactions with the surrounding environment, affecting both inside and outside surfaces of the metallic structure.

The most common and effective industrial technique to prevent corrosion involves implementing cathodic protection (CP) systems. These systems control the entire environment of metallic corrosion by minimizing the potential difference between the metallic structure and the reference cell [3]. The CP system is regulated by the current injected from a transformer rectifier unit or the power supply itself, aiming to limit metal corrosion in pipeline networks [4]. However, periodic on-site inspections and offline recording methods of the CP system are not effective in monitoring sudden and occasional pipeline failures. Therefore, data integrity is crucial, and no data loss can be tolerated during manual inspection and recording. Even minor hassles can significantly impact the accuracy and consistency of data collection. Consequently, transitioning the monitoring system from manual to real-time remote monitoring will enhance the effectiveness of this CP system. The remote monitoring unit (RMU) automatically collects CP data from various sensors, transmits all measurements via a communication network or protocol, and intreprets these measurements using an industrial internet of things (IIoT) platform for the CP operators. This integrated system ensures continous monitoring and assessment of the CP system, streamlining data collection from multiple test posts and providing the operaters with a proactive real-time surveillance system.

## II. BACKGROUND STUDY

### A. Cathodic Protection

Cathodic protection (CP) is a proven corrosion management technology for subterranean and undersea metallic structures, such as oil and gas pipelines, cables, utility lines, and foundations. Additionally, various structures such as, oil drilling platforms, dockyards, jetties, ships, submarines, condenser tubes in heat exchangers, bridges, decks, civil and military aircraft, and ground transit systems are protected with a cathodic protection. There are two common types of CP systems: sacrificial anode (SA) and impressed current (IC) systems. The CP system is regulated in three different ways: by controlling the protection current, protection voltage or potential, and regulated voltage of the protected metallic structure. The level of applied current is crucial, as a low current may not adequately protect the pipeline, and excessive current can lead to material degradation and premature failure of the pipeline [5].

### B. Remote Monitoring

With disasters such as the recent Coronavirus outbreak, ensuring the safety and health of metallic assets becomes

increasingly critical. Remote monitoring enables the transportation and distribution of liquid and gas utilities to continue operating during such events. This allows operators to safely and remotely monitor assets, adhering to social distancing measures while ensuring business continuity. The most recent technology introduced for monitoring assets in the corrosion industry is the industrial internet of things (IIoT). This technology enables operators to remotely monitor the CP system of metallic structures. The framework for a remote monitoring CP system using IoT technology was introduced through a complex control system [6]. The proportional-integral-derivative (PID) controller system determines the CP parameters through trial and error, maintaining a minimum potential value to protect the metallic structure from corrosion. This system focuses only on controlling the voltage of the protected metallic structure.

Meanwhile, a remote monitoring system has been developed to measure a variety of essential parameters in the protection of metallic structures. This system monitors on a continuous or scheduled basis using a GSM communication protocol [5,7]. However, since negative potential is a crucial parameter representing the CP conditions, an additional operational amplifier (op-amp) needs to be attached to a microcontroller to meet the CP's requirements. Furthermore, an IoT-based power measurement unit has been developed. This unit, based on a microcontroller platform, is web-based and includes an embedded electronic system of meters and sensors [8,9]. These IoT-based systems could be implemented for remote monitoring of the CP system, as both circuits solely function to measure current and voltage.

## III. ONLINE-ENABLED REMOTE MONITORING SYSTEM

### A. Block Diagram of Remote Monitoring System

An automatic remote monitoring system consists of three modules, namely as, remote measurement unit, communication network and dashboard monitoring unit, as shown in Figure 1.
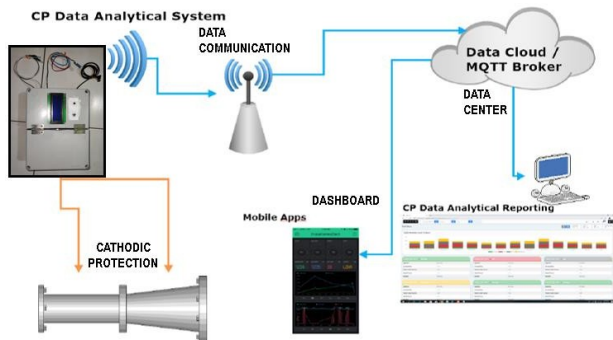


Fig. 1. An automatic test post remote monitoring system

The main function block of the remote monitoring system is a standalone and self-powered remote measurement unit, as shown in Figure 2. This unit is controlled by a low-power system-on-a-chip microcontroller with an integrated GSM module (ESP32). Three sensors are deployed in the unit: a voltage sensor for performing potential measurements for CP, a humidity sensor for measuring soil moisture surrounding the metallic structure, and a gauge sensor attached to the lithium-ion battery to monitor the battery's capacity. The system's real-time data measurement and logging capability are set to intervals of 100 ms (10 data points per second). The unit's data communication is facilitated through GSM and is connected to the MQTT broker server on Node-RED, interfacing via a Node-RED dashboard on a Raspberry Pi terminal window. Using a browser, Node-RED enables the construction of functionality by connecting data flows across nodes and simulating application bits between the three sensors.
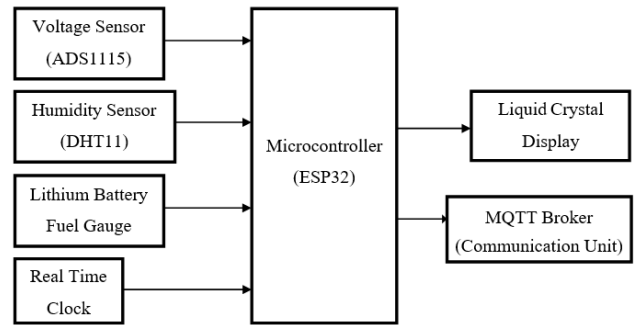


Fig. 2. Block diagram for a remote measurement unit (RMU)

### B. Hardware Development and Experimental Setup

The prototype remote monitoring system consists of a combination of hardware and software required for collecting, transmitting and storing potential measurements from voltage sensors at a designated test post within a CP system. Figure 3 shows the hardware implementation of the RMU, while Figure 4 provides an internal view of its components. The lithium-ion battery and remote measurement unit were placed side by side in the junction box. The humidity sensor probe is buried in the same place as the metallic structure, while the voltage sensor probes are connected to the metallic structure and reference cell for potential difference measurement as an important CP parameter.
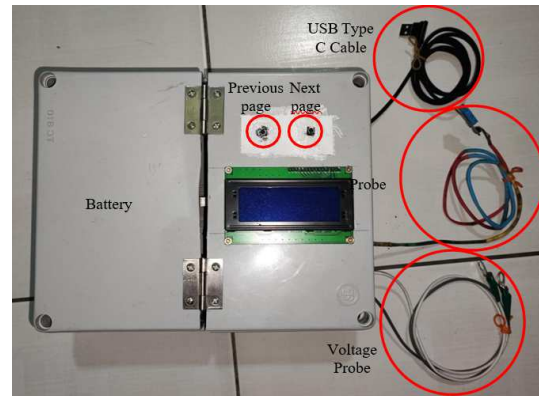


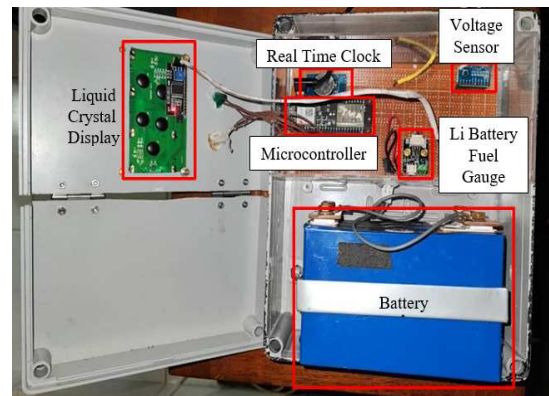Fig. 3. External view of the RMU Casing



Fig. 4. Internal view of RMU components

Figure 5 illustrates the layout of the experimental setup for measuring the CP system. This setup comprises a DC power supply, an anode bed, a steel pipe (cathode), a reference cell (PRE or RE), and interconnecting cables. As depicted, the negative terminal from the DC power supply is connected to the steel pipe, while the positive terminal is connected to the anode [10]. The anode bed functions as an electrolytic cell and serves as a terminal current entry in the CP system. The steel pipe, acting as a cathode, provides the metal surface that is being protected from corrosion. This is achieved by forcing the anode bed to corrode in its place. The potential difference between the anode bed and the cathode represents the electromotive force and can be measured as voltage. Meanwhile, the PRE or RE is used to measure the potential difference of the protected metal surface (cathode). It is a crucial component for monitoring the effectiveness of the CP system, providing a stable and constant reference potential for accurate measurements. Therefore, precise measurements of these voltages are vital in determining the level of corrosion and assessing whether adequate protection is being provided to prevent corrosion of the metal surface. The voltages, serving as CP parameters, are monitored by measuring and logging the difference in potential difference in millivolts (mV) between the metal surface and the PRE or RE. Figure 6 presents the actual experimental setup of the CP system. The specification of voltage and current values for the DC power supply is 13.0 V and 1.58 A, respectively.
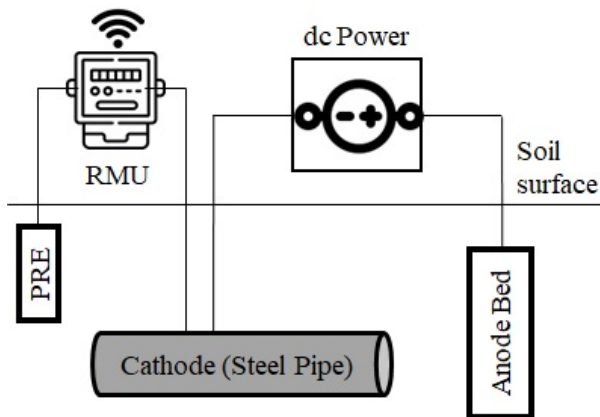


Fig. 5. The layout of cathodic protection system



Fig. 6. The experimental and measurement setup

## IV. MEASUREMENT AND TESTING

### A. Potential Difference Measurement

Potential measurements were taken between the corrosion-free steel pipe and the corroded steel pipe, respectively, with respect to the PRE. Both measurements were continuously taken for 15 seconds within a 10-second interval using both the RMU system and a digital multimeter (DMM). In the conventional reading approach, an operator of a CP system uses the DMM to measure the potential difference between pipeline and the PRE. Table 1 and Table 2 present the differences between the DMM and the RMU for corrosion-free and corroded steel pipes, respectively. The percentage error (%) was calculated as in (1) to evaluate the relevance of the results.

$$Error\ (\%) = (RMU_{measured} / DMM_{measured}) \times 100 \quad (1)$$

Table 1 reveals that the RMU demonstrated potential measurements similar to the DMM readings, with differences ranging from 1 to 5 mV and an average difference ($\Delta$mV) of 2.9 mV. Meanwhile, the measurements in Table 2 indicate that the RMU's measurement for the corroded steel also exhibits an average $\Delta$mV of 1.5 mV compared to the DMM. Both sets of measurements maintain a resolution within 5 mV of the DMM readings. Furthermore, both results show errors below 1%, which indicate that the potential measurements using the prototype RMU are acceptable. Additionally, the potential measurement for corroded steel was significantly higher than that for corrosion-free steel because corrosion-free steel consumes more current than corroded steel.

TABLE I.          MEASUREMENT OF CORROSION-FREE STEEL TO PRE

| Potential Difference Measurement | | | |
|---|---|---|---|
| *DMM (mV)* | *RMU (mV)* | *\|ΔmV\|* | *Error (%)* |
| -1050 | -1048 | 2 | 99.81 |
| -1046 | -1051 | 5 | 100.48 |
| -1048 | -1044 | 4 | 99.62 |
| -1039 | -1042 | 3 | 100.29 |
| -1036 | -1038 | 2 | 100.19 |
| -1042 | -1047 | 5 | 100.48 |
| -1049 | -1045 | 4 | 99.62 |
| -1037 | -1039 | 2 | 100.19 |
| -1039 | -1040 | 1 | 100.10 |
| -1047 | -1048 | 1 | 100.10 |

TABLE II.          MEASUREMENT OF CORRODED STEEL TO PRE

| Potential Difference Measurement | | | |
|---|---|---|---|
| *DMM (mV)* | *RMU (mV)* | *\|ΔmV\|* | *Error (%)* |
| -3152 | -3151 | 1 | 99.97 |
| -3149 | -3149 | 0 | 100.00 |
| -3150 | -3148 | 2 | 99.94 |
| -3177 | -3175 | 2 | 99.94 |
| -3163 | -3162 | 1 | 99.97 |
| -3157 | -3158 | 1 | 100.03 |
| -3159 | -3160 | 1 | 100.03 |
| -3149 | -3151 | 2 | 100.06 |
| -3185 | -3187 | 2 | 100.06 |
| -3179 | -3176 | 3 | 99.91 |

## B. Polarization and Depolarization Potential Behavior

The RMU was utilized to conduct various tests in the CP system. These tests measured the potential difference between the RE and the anode, the RE and the steel pipe, and the RE and the anode with the steel pipe (anode+pipe), to exhibit potential behaviors. The RMU was capable of taking measurement readings at intervals of up to 100 ms, enabling the monitoring of polarization and depolarization potential behavior in the CP system. Figure 7 presents the recorded readings of the potential difference between the RE and the anode. The RMU displays a constant reference voltage of –1500 mV between these two electrode components, indicating an open circuit measurement [11]. Figure 8 shows the measurement results from the RMU for the potential difference between the RE and the pipe. The RMU recorded voltage values ranging exponentially from -745 mV to -705 mV. This reflects the level of cathodic protection provided to the pipe and depends on the types of reference electrodes in CP, including magnesium, copper/copper sulfate, and zinc [12]. Figure 9 presents the measurement results from the RMU's recorded readings when the anode is connected to the pipe with reference to the RE. The RMU recorded voltage values ranging exponentially from -720 mV to -770 mV, indicating a shift in the potential of the pipe to a more negative value. This shift in potential or voltage, known as polarization behavior, and the reverse effect, known as depolarization behavior, is the reduction of the polarization level closer to its natural state [13].
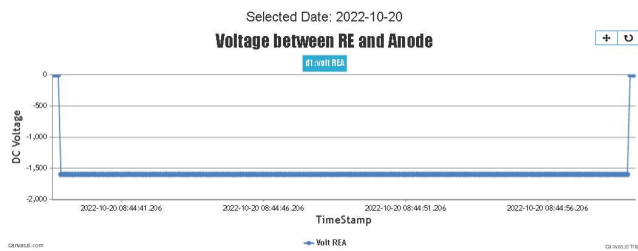


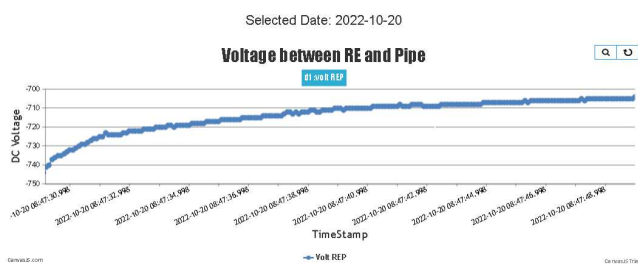Fig. 7. Potential difference between RE and anode



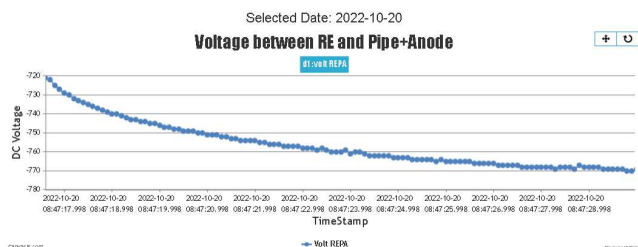Fig. 8. Potential difference between RE and pipe



Fig. 9. Potential difference between RE and anode

A similar remote monitoring of oil pipelines' cathodic protection system was developed using a ThingSpeak, web-based IoT platform [14,15]. This system provides real-time monitoring of instantaneous potential voltage levels with an accuracy rate of up to 99.7% compared to DMM readings [14]. However, this particular remote monitoring system primarily focuses on sending alerts by SMS and e-mail when potential values exceed or fall below certain threshold values. In constrast, the RMU system developed in this work not only exhibited a high accuracy rate for potential measurements but is specifically designed for monitoring the polarization and depolarazation potential behavior in the pipeline surroundings during the application of the cathodic protection system. The logging capability of 10 data points per second enables monitoring of detailed changes in potential values under CP conditions on the pipeline. Finally, Figure 10 shows that the RMU system also provided dashboard information for humidity, temperature, and battery capacity values to monitor the environment and battery consumption, respectively.



Fig. 10. Dashboard for humidity value and battery capacity

## V. CONCLUSIONS

In summary, the development of the RMU system integrated an IIoT platform enables real-time and on-site monitoring of potential measurements between the pipeline and the reference eletrode. The RMU is capable of measuring, transmitting and interpretting data measurements for online surveillance of the cathodic protection operating conditions on the pipeline. The developed remote system accurately measured instantaneous potential levels in real time, which exhibited a remarkable low error within 1% (with a range of $\Delta$mV 1.5 to 2.9 mV) compared to the DMM readings. Additionally, the online dashboard facilitates monitoring of various potential differences, including polarization and depolarization behaviors due to cathodic protection operating conditions. Thus, this prototype system also enables effective and consistency data recording for corrosion prevention and mitigation. Furthermore, the system also successfully monitored temperature, humidity, and battery capacity, allowing operators to periodically assess environmental conditions at the test post and the battery consumption of the RMU, respectively.

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