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PIPELINE CORROSION PREVENTION SYSTEM

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Abstract. *The corrosion analysis in buried pipelines aims the correct maintenance of pipelines allowing the uninterrupted flow of production. However, the difficulty of access and the need for constant inspection become an obstacle to the correct maintenance flow chart. Buried pipelines are commonly exposed to an aggressive environment with climatic variables that accentuate the process of corrosion in buried metals. This study aims to develop a fully autonomous corrosion avoidance system with an on-line monitoring in compliance with 4.0 industry. This work aims to present low cost and reliable solutions, allowing the system expansion according to the needs of the pipeline extension. By using the nationwide broadband mobile network to communicate with a remote server. The system enables rapid data acquisition and remote intervention according to climate change if necessary.*

Keywords: *Corrosion protection, Pipeline, Online monitoring systems, 4.0 industry*

1. INTRODUCTION

Corrosion is a major cause of equipment deterioration, metal and concrete structures, whether in transmission lines towers or buried pipelines, resulting in high maintenance costs and even the supply interruption of industry production. The corrosion process is an advanced stage of a physicochemical oxidation reaction between materials with different potentials that culminates in the loss of active material. In the case of transmission line towers, specifically those with metal grilles, the material loss is exactly that which is the tower's support base material. In extreme cases the structure can reach such a high point of deterioration that an interdiction is required. The damage involved in these cases are so high that maintenance ceases to be a viable option.

According to CETESB, between the years of 1980 to 2006, were recorded 178 cases involving pipeline ruptures in the state of São Paulo, among which 57 accidents occurred due to pipeline corrosions. The state of São Paulo has a total of 4,652.5 km of pipelines. In comparison, the national pipeline network has more than 21,000 km distributed among air, submarine and buried pipelines. In order to ensure a standardized maintenance procedure, the Brazilian regulatory standards, NBR's, published by the Brazilian Agency of Technical Standards, establish rules, guidelines and procedures to be followed with the intention of avoid failures and incompatibilities during industrial and laboratory processes. For the regulation of external corrosion prevention in pipelines through coating and cathodic protection system (SPC), there are the standards NBR ISO 15589-1: 2012/16 which is a literal translation of the standard ISO 15589-1 Petroleum, petrochemical and natural gas industries - cathodic protection of pipeline transportation systems - Part 1: On - land pipeline. As well as ABNT NBR 6181: 2003 standards responsible for characterizing corrosive environments, ABNT NBR 16172:2014 which instructs on the discontinuation of anti-corrosion coatings applied on metallic substrates, ABNT NBR 16265: 2014 which determines how anodes should be inspected for cathodic protection. These standards do direct reference to pipeline protection, the printed current cathodic protection system and maintenance of anode banks alongside a pipeline.

Therefore, to implement a monitoring system capable of matching the needs for a maintenance team and drawing up an appropriate action plan accounting the aspects for each soil segment is a complicated task. In some cases, the ducts sites are difficult to reach, thus it is of fundamental importance to facilitate the inspection for the pipelines condition and decrease maintenance costs (ARAÚJO, 2012). Monitoring the operating conditions of a pipeline depends directly on the environment, since climatic issues and leakage currents are mainly responsible for the aggressive corrosion in buried ducts making active monitoring difficult when it comes to long distances pipelines. There are options for on-line monitoring like satellite or cable connection. However, the high prices become an impediment. A viable solution within easy reach are mobile phone networks. Whether in urban or rural areas, the availability of mobile operators exists. Using a system that allows for wide connection availability is essential for monitoring stability and reliability.

2. METHODOLOGY

2.1 Circuit Power

In order to allocate power to the sensors and control boards, an electrical scheme was designed using EasyEDA software. Placing 15 volts and 8 ampere switched-mode power supply (SMPS) source as the power input. Two diodes are placed in the circuit input for polarity reversal protection. The LM7809 voltage regulators were used to power the control board arduino mega 2560 R3. The LM7805 regulator were employed to power the mobile telephone network board (Gsm Gprs Shield Sim900 module) and an LM7805 to power three AC voltage sensors, an AC current sensor and a DC current sensor. At each output connector, LEDs were added to indicate system operation.

The Gsm Gprs Shield Sim900 module power system presents a particular solution since the operation of this module requires 2 amperes current peaks to perform correctly. An LM7805 regulator offers a maximum current of 1A (one amp), so to obtain a higher current of these integrated circuits a PNP TIP127 transistor was used as booster, allowing a regulated output of 5 volts and a maximum current of 5 amperes. The power supply system circuit is shown in Fig. 1.

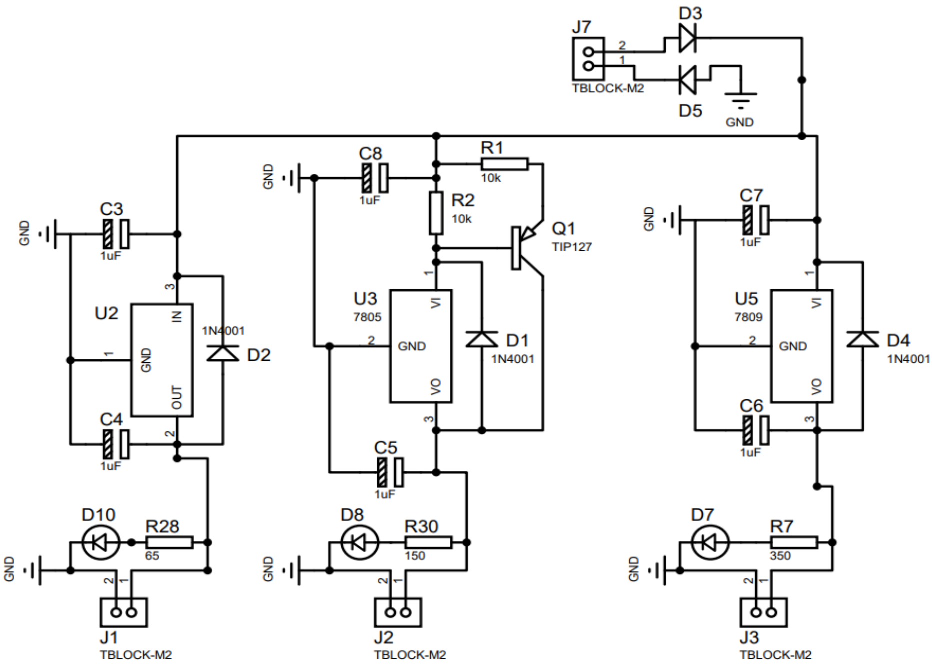

Figure 1. Power supply diagram. Source: Author (2019).

2.2 Buck Circuit

With the purpose of avoid corrosion of buried ducts placing a printed current, a potential control between the anode bank and the duct is required. A BUCK circuit, Figure 2, was designed and with a drive controlled by the Arduino Mega 2560 R3 control board.

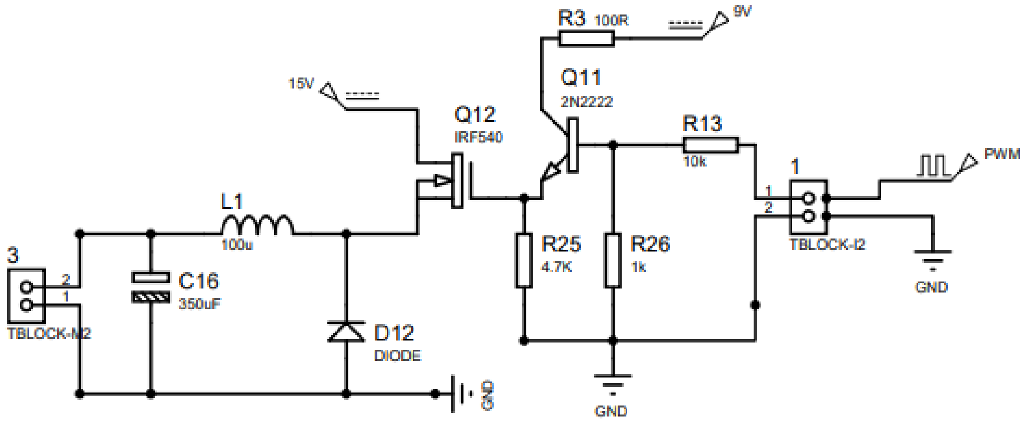

Figure 2. BUCK circuit. Source: Author (2019).

The buck circuit features the control of the output voltage through the drive circuit's switching the frequency by a PWM waveform. In this case, a 2n2222 transistor was used as a switch to drive an IRF540 MOSFET. The Pulse Width Modulation (PWM) wave, characterized by the pulse width of a wave, when at high frequency, has an average voltage that can be calculated by Equation (1), where T corresponds to the square wave period, T_{on} corresponds to the time where the wave has its maximum value and V_{Max} at the maximum wave voltage, as shown in Fig. 3.

$$V_{average} = \frac{T_{on}}{T} \times V_{max} \quad (1)$$

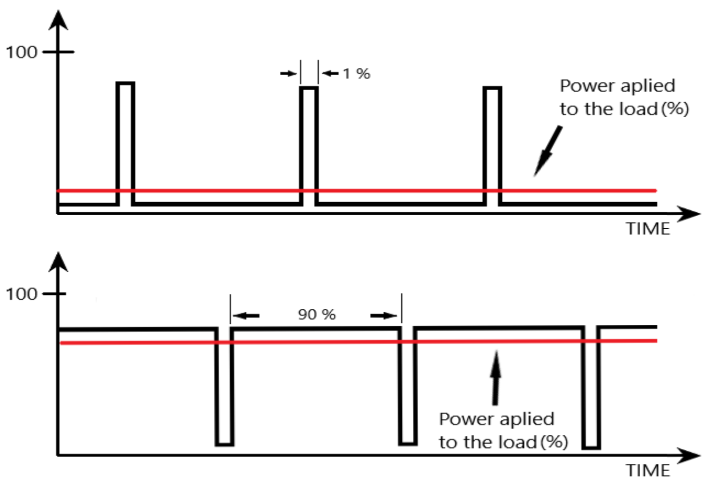

Figure 3. PWM wave form. Source: Author (2019).

During the period in which the wave value is zero and the switch is open there is no current flow. Therefore, current ripple occurs, there are periods where the switch is closed allowing current to pass and periods where the switch is open and preventing current from passing. During the time the key is closed and therefore conducts power, the inductor stores part of the charge in magnetic field which is discharged when the key is opened. This process called current ripple can be calculated by Equation (2); i_{max} is the maximum current pass through the inductor; i_{min} represents the minimum current in the inductor; t_{off} the time the switch remains open; L is the inductor (coil) inductance.

$$i_{max} - i_{min} = \frac{V_{max} + t_{off}}{L} \quad (2)$$

2.3 Soil Resistivity

Soil has a very heterogeneous composition, and the value of its electrical resistivity can vary from place to place depending on the type, moisture level, depth of the layers, age of geological formation, temperature, salinity and other natural factors, as well as external factors such as contamination and compaction (NBR 7117, 2012). A wide range of soil resistivity values ranging from 10 to 2,000,000 Ω × and a strong dependence on the amount of water present in on soil is observed by Tab. 1. Considering that a majority soils are heterogeneous and formed by different layers of resistivities and different depths, these layers, due to geological formation, are usually horizontal and parallel to the soil surface. However, there are also cases where, due to some geological fault, these layers are inclined and even vertical.

Table 1. Material resistivity values. Source: NBR 7117.

MATERIALS	RESISTIVITY (Ω × m)
Sea water	under 10
Distilled water	300
Mud	150
Clay	300 - 5.000
Limestone	500 - 5.000
Sand	1.000 - 8.000
Basalt	above 10.000

Measurement of soil resistivity is done by sampling or local measurement. The first one is carried out in the laboratory and the second one by the imposition of electromagnetic signals in limited regions of the soil, through electrodes suitably positioned in this environment, and by the detection of the potentials established in the vicinity.

For the local soil resistance measurement, a few methods can be used, among which:

- Wenner method;
- Lee method;
- Schlumbeger - Palmer method;

In this work the Wenner's method were performed. the Wenner's method consist in four rods equally spaced and inserted at the same depth, represented in Fig. 4.

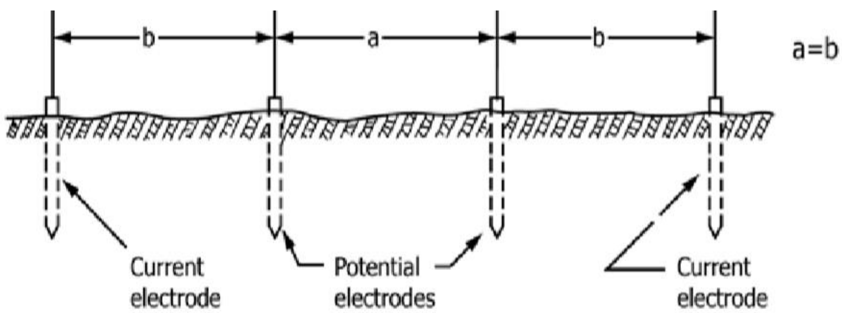

Figure 4. Wenner soil resistivity measurement method. Source: ASTM G57-06.

An electric current is injected at point 1 by the first rod and collected at point 4 by the last rod. This current, passing through the soil between points 1 and 4, produces potential in points 2 and 3. Equations 3 and 4 are shown.

$$V_2 = \frac{\rho \times I}{4 \times \pi}\left(\frac{1}{a} + \frac{1}{\sqrt{(2a)^2+(2p)^2}} - \frac{1}{a} - \frac{1}{\sqrt{a^2+(2p)^2}}\right) \quad (3)$$

$$V_3 = \frac{\rho \times I}{4 \times \pi} \left(\frac{1}{2a} - \frac{2}{\sqrt{(2a)^2 + (2p)^2}} + \frac{2}{\sqrt{a^2 + (2p)^2}} \right) \tag{4}$$

Thus, there is a potential, Equation 5, difference between points 2 and 3:

$$V_{23} = \frac{\rho}{4 \times \pi} \left(\frac{1}{a} - \frac{2}{\sqrt{(2a)^2 + (2p)^2}} + \frac{2}{\sqrt{a^2 + (2p)^2}} \right) \tag{5}$$

2.4 Data Acquisition and Control System

For the system control, the Arduino mega 2560 R3 was used, with ATmega2560 microcontroller and 54 digital ports, of which 15 can be used as PWM, plus 15 analog ports. 16 Mhz clock, USB connection and external power connector. The control board has a 10-bit digital analog converter for data captured via sensors. The digital ports were used to connect a 4-relay module and the mobile phone network module. The control board has an integrated development interface and is a platform application written in the Java programming language. This aplication is used to write and load codes on Arduino through the C and C ++ programming language.

The module ZMPT101B with reading accuracy of 0.95% is appropriate to measure the voltage potential between the electrodes in the Wenner ground resistivity method while the AC - ACS712 Current Module makes it possible to read alternating current through a hall effect sensor. To check the potential between the soil and the buried pipeline a standard copper sulfate electrode, Figure 5, electrode was used.

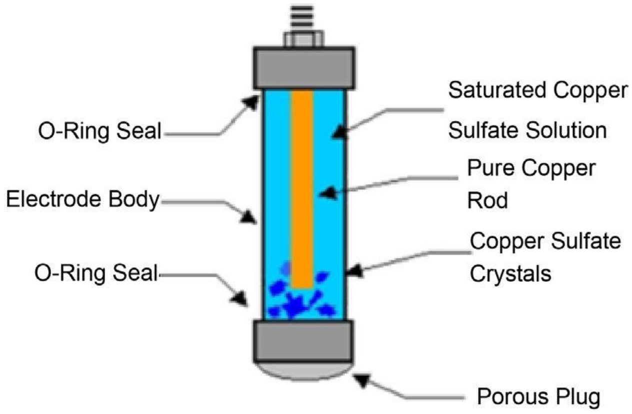

Figure 5. standard copper sulfate electrode schematics. Source: https://www.researchgate.net/figure/The-Cu-CuSO4-reference-electrode_fig3_333797979

For the data acquisition storage, a hosting service were used. The database was created using the MySQL language with the help of phpMyAdmin platform as shown in Fig. 6.

Within the server database, seven entities were created, divided as follows.

- ID - Data Identifier: It has a +1 auto-increment function. With each new data acquisition loop, the identifier changes its number preventing a previous reading being overwrite by a new one.
- Date_Time: Each time the mobile internet communication module makes a new request or annotation in the database, the day and time these actions were performed are recorded.
- Value_1, Value_2, Value_3: Space for storing data measured by AC voltage sensors, responsible for the operation of the ground resistivity monitoring system.
- AC Current: Location for storing data obtained through the AC current sensor.
- DC voltage: Storage location for data obtained through the DC voltage sensor.

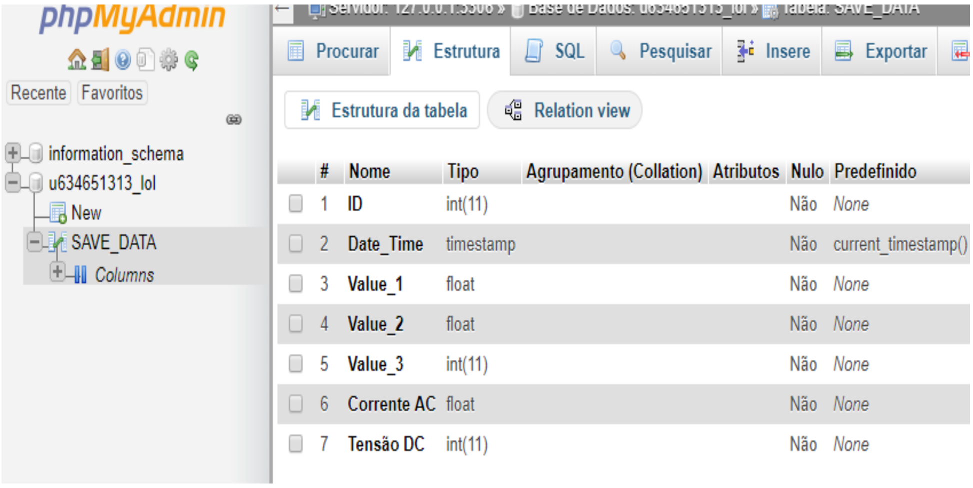

Figure 6. Database. Source: Author (2019).

2.5 Test method

The methodology consists of experimental testing of the proposed system and reliability compared to the tests conducted by a commercial equipment. During the tests, rods distance of 2, 4, 6, 8 and 10 meters, respectively, was used. Readings performed by commercial equipment and by the developing equipment were stored. To perform the tests, rods in carbon steel (SAE 1010/1020), with electrolytic copper coating of minimum purity of 99.9%, were used. The data obtained were compared with the data sent to the server by the system.

After the measurements, an analysis of the results was made so that the results can be evaluated for acceptance or not, as detailed below. The arithmetic mean of the resistivity values for each adopted spacing was calculated by Equation 6, where $\rho_M(a_j)$ is the average resistivity for the respective distance (a_j); n is the number of measurements made for the respective spacing (a_j) and (q) is the number of spacings employed.

$$\rho_M(a_j) = \frac{1}{n}\sum_{i=1}^{n} \rho_i\,(a_j) \quad \forall \quad \begin{cases} i = 1, n \\ j = 1, q \end{cases} \tag{4}$$

All resistivity values that deviate more than 50% from the average rate should be disposed. If the resistivity value has a deviation below 50% the value will be accepted as representative. If a large number of measurements with deviations above 50% occur, new measurements will be performed in the corresponding region. If the occurrence of deviations persists, then the area should be considered as an independent region for modeling purposes. With the new table, the arithmetic averages of the remaining resistivities are calculated. With the average resistivities for each spacing the curve $\rho \times a$ will be plotted.

3. RESULTS

Were compared the data obtained by the commercial MEGGER equipment with data sent to the server by the prototype monitoring system created in this work. In Table 2 are shown the results recorded by the commercial Megger.

Table 2: Results recorded by the commercial Megger.

SPACE (m)	READING (R)	RESISTIVITY (P)	DEVIATION	RELATIVE DEVIATION (%)
2	8,99	112,91	109,38	3,12
4	4,1	102,99	99,46	3,42
6	2,5	94,20	90,67	3,74
8	1,28	64,30	60,77	5,48
10	0,78	48,98	45,45	7,20

Test, Figure 7, are shown below:

Figure 7. Commercial Megger tests**.** Source: Author (2019).

Table 3 shows the results obtained by the system developed in this work and Figure 8 shows the system developed in this project.

Table 3: Results recorded by the system developed in this work.

SPACE (m)	READING (R)	RESISTIVITY (P)	DEVIATION	RELATIVE DEVIATION (%)
2	8,73	109,64	106,22	3,12
4	3,98	99,97	96,54	3,42
6	2,45	92,31	88,88	3,71
8	1,24	62,29	58,86	5,50
10	0,74	46,47	43,04	7,37

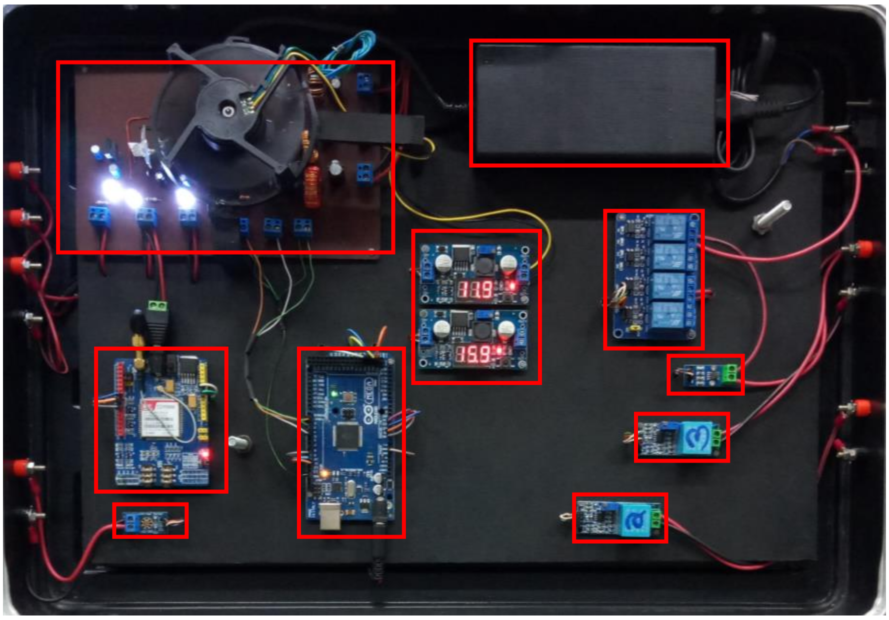

Figure 8. Developed equipment. Source: Author (2019).

Figure 9 shows the comparison of resistivity (ρ.m) as a function of rod distance for the five tests performed with the commercial equipment (blue color) and the system developed in paper (red color).

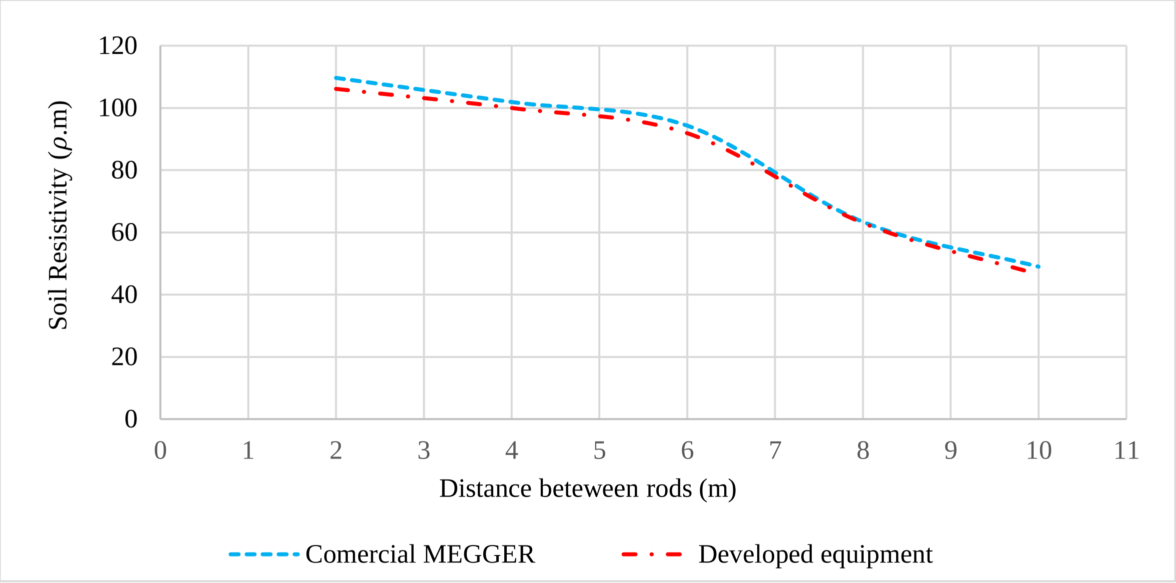

Figure 9. Graphic plot $m \times \rho.m$. Source: Author (2019).

The monitoring and corrosion control system proposed in this work proved to be very promising. The results obtained by the system are compatible with the results obtained by the commercial Megger. Further study of the reliability of the new system requires further field testing as well as the development of a more robust database to save test data over months. The data process and analysis sent by the sensors to the server needs to be better developed so that the system can become completely independent.

4. ACKNOWLEDGEMENTS

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6. RESPONSIBILITY NOTICE