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CASE STUDY FOR UPGRADING THE DESIGN OF IMPRESSED CURRENT CATHODIC PROTECTION FOR TANK BOTTOMS AS AN EXTERNAL CORROSION CONTROL METHOD

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ABSTRACT

Engineering design calculations for tank bottom sections, including direct current requirements and voltage calculations, followed by additional structures, such as electrical grounding systems, have already been successfully implemented and controlled in field conditions. Furthermore, the effect of soil resistivity in layers, oxygen content and the pH value of the soil against the disproportionate IR-Drop voltage, including its effect on potential distribution, have been already successfully observed. Other influences, such as the depth and location of the anode groundbed determination along with the establishment of impressed current cathodic protection related to the main tools and equipment, such as external corrosion control methods, have been defined as the most effective ways in order to control potential distribution against the additional structures. Persuant to the verification results from the site located at Marangkayu, East Borneo, it has been determined that high soil resistivity could cause error readings in accordance with the accumulation results of the true readings and the IR-Drop voltage, since under real conditions, the tank structure would have received less current flow from an anode compared to a lower result. Naturally, a low pH value from the soil would decrease soil resistivity and enhance potential distribution from the anodes to the tank structures. The results show that the cathodic protection required 10 additional anodes, (each one is of a tubular *mixed metal oxide*) with a DC supply at minimum amperage of 154 Amps and a minimum voltage supply of 32 Volts. During the research, it was identified that high soil resistivity above 3000 ohm-cm would cause error readings. Naturally, acidic soil is in the region of pH 5‒7 value, which would decrease soil resistivity and enhance the potential distribution from the anode to the tank structure.

Keywords: Aboveground storage tank; Engineering design; Impressed current cathodic protection; Potential mapping; *Voltage drop*

1. INTRODUCTION

Storage facilities for petroleum products usually consist of a collection of aboveground storage tanks called a tank farm. The tank bottom is subject to the same corrosion issues as are buried pipelines. The provision of cathodic protection to tank bottoms is, if anything, more critical than is the provision of cathodic protection to pipelines. The performance of a cathodic protection system is closely related to the achievement of a minimum protection level through the structure to ascertain the potential electrolyte measurement (-850mV vs CSE). There are many parameters which will effect the cathodic protection system and the current demand, such as soil resistivity, coating performance, pH level, or the Sulfate-Reducing Bacteria (SRB) content

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inside the electrolyte environment (Fontana, 2005). Hence, an investigative study is required to observe the main characteristics which are explained above and are being implemented to the system design of a cathodic protection system for external corrosion control in order to protect the tank bottoms of the aboveground storage tanks located at Marangkayu, East Borneo, Indonesia (T-1301 A/B/C/D and AB Rerun Tanks). The tank locations are seen in Figure 1 below.

Figure 1 Marangkayu location (Left), tank structures in Google map view (Right)

Based on the latest inspection data, almost all of tank structures are standing aboveground below the minimum protection level. Existing cathodic protection systems, which are protecting all of the tanks, have already been in operation for the past 8 years. However, the transformer rectifier does not seem to be rated at the maximum condition. Based on this explanation, it is necessary to investigate the reasons and then perform an upgrade for the cathodic protection system for all of the tanks, which needs to last for the next 20 years. This research was conducted to determine the engineering design system, including the installation of an impressed current cathodic protection system at the T-1301 A/B/C/D and the AB Rerun Tank at Company PT XX in East Borneo. The research was not only limited to the current demand for all of the tanks, but also it analyzed external factors, such as the environment, which have a significant effect on cathodic protection performance. As a part of the research verification process, the most important external factor involved the investigation of anomaly data, which occurred during the commissioning process.

This research aims to provide an improved understanding of the design of impressed current cathodic protection systems. A single tank was modeled and protection was provided by a series of anodes distributed around the circumference of the tank. The analysis was related to the direct effect from the environmental conditions of the pH values, soil conditions, and O_2 content on the oil and gas tank farm applications.

2. EXPERIMENTAL PROCEDURES

Mild carbon steel ASTM A-36 was used in this study as the material for the storage tanks structures. The anode type was a tubular *mixed metal oxide*. The flowchart of experimental procedures is shown in Figure 2.

The research method started with a preliminary site survey for collecting primary data for the structures. This step included determining variables for the actual soil resistivity values, based on the proposed groundbed location.

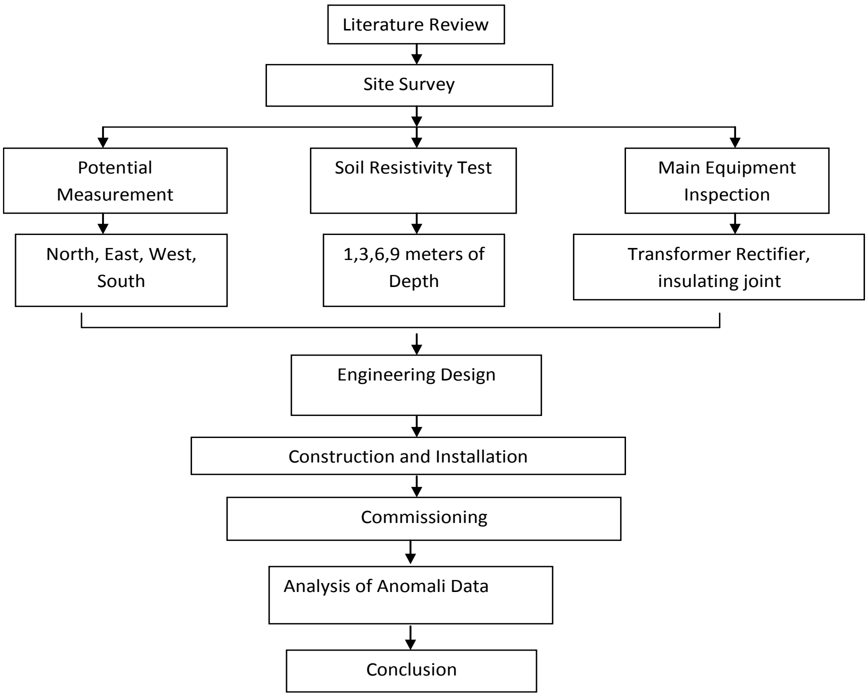


Figure 2 Flow chart of experimental procedures

Additional steps involved assessing the *structure to electrolyte* potential measurements and investigating the location of current cathodic protection equipment, such as the transformer rectifier, the junction box and the anode groundbed. Furthermore, the engineering design and anomaly data analysis was built as a part of the investigative research study. The soil environment for all structures was considered to be free from Sulfate-Reducing Bacteria. Verification parameters from this case study are limited to the *structure to electrolyte potential*, related to environmental conditions such pH values and soil resistivity.

3. RESULTS

3.1. Design Proposed

Table 1 has defined the cathodic protection design parameters that were utilized within this research.

Table 1 Design parameters

Current density	Coating breakdown	Soil resistivity	Design Lifetime
For Steel Bottom Tank: 20 mA/m^2 For Copper Electrical Grounding: 19mA/m^2	For A/B/C/D” Tank: 20% For AB Rerun: 100%	1000 ohm-cm	20 years

Within this investigative research, there are several additional electrical grounding systems. It is important to note that in the electrical grounding system, copper acts as the metal which is automatically covered by the cathodic protection systems. Therefore, the addition of copper as a material for part of the metal structure is deemed necessary (Peabody, *2007*).

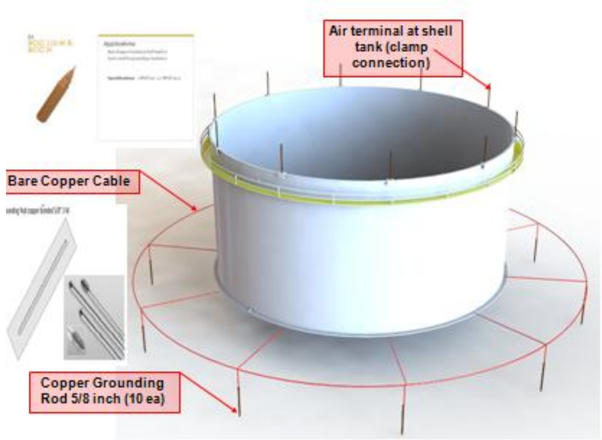


Figure 4 General layout of existing lightning protection systems

The current requirement could be calculated by using Equation 1 as shown below (Peabody, 2007):

$$It = S/A \times (Cd/1000) \times Cb \times (1+Sf) \tag{1}$$

where;

It : Current Demand (A)
S/A : Surface Area (23,425.9 m^2)
Cd : Current Density (20 mA/m^2)
Cb1 : Coating breakdown (100% for AB Rerun Tank)
Cb2 : Coating breakdown (20% for A/B/C/D Tanks)
Sf : Safety factor (125%)

The total current requirement for protecting all of the structures is 154.3 A. (This design parameter is already stated in Table 1). This impressed current cathodic protection system is used to protect the bottom steel section of the T-1301 A/B/C/D and AB RERUN tanks and it will utilize in total thirty-three (33) anodes in the system, of which 23 of them are defined as existing anodes. The impressed current system was used for a shallow anode groundbed. There are a total of 33 groundbeds which are being supplied by one (1) transformer rectifier. The current output for each anode will be 4.89 A; therefore, the total current output for each groundbed will be 161 A. The classification of the anode number is shown below in Table 2. Further, the spots of EDS testing are depicted in Figure 1, as follows:

Table 2 General arrangement of anode distribution

No	Structures	Existing anode(ea)	New anode(ea)	Total(ea)
1	T-1301 A	5	2	7
2	T-1301 B	5	2	7
3	T-1301 C	5	2	7
4	T-1301 D	5	2	7
5	T-1301 AB RERUN	3	2	5
Total		23	10	33

And by using Equation 2 as shown below (Peabody, 2007):

$$R_a = \frac{\rho\alpha}{2\,\pi\ .L_a} . \left(Ln\ .\left[\frac{8\ L_a}{\varnothing_a} \right] - 1 \right) \tag{2}$$

$$R_b = \frac{\rho\beta}{2\,\pi\ .L_b} . \left(Ln\ .\left[\frac{8\ L_b}{\varnothing_b} \right] - 1 \right) \tag{3}$$

where;

R_a : Anode to backfill resistance (ohm)
R_b : Groundbed to soil resistance (ohm)
ρ_a : Soil resistivity (ohm.cm)
ρ_b : Backfill resistivity (20 ohm.cm)
L_a : Anode length (m)
L_b : Length of canister (m)
$\varnothing_a$: Anode diameter (m)
$\varnothing_b$: Canister diameter (m)

The total resistance of the overall systems is defined as 0.1535 ohm, and the total direct current voltage rating of the power supply is defined as 31.6 V. Therefore, the transformer rectifier rating required for the new system will be 100V and 200, respectively.

3.2. Verification Results

The Native Potential Measurement has been taken and the results are as shown in Figure 5 below:

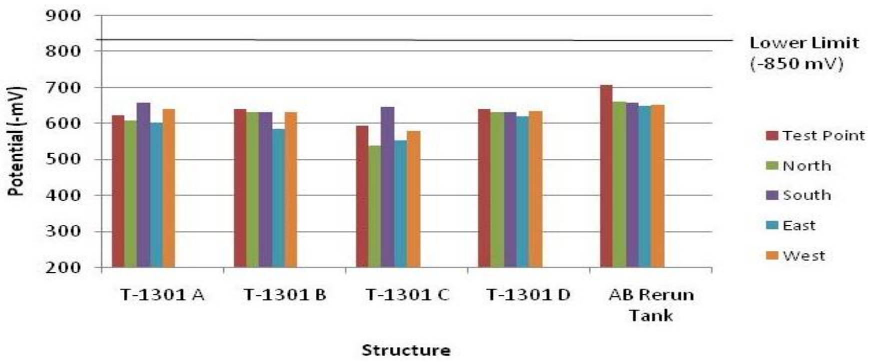


Figure 5 Native potential results [mV]

Based on above graph, it can be seen that all of potential structures still stand below the minimum protection level (-850 mV). Afterwards, the transformer rectifier is energized and allowed to run in the polarization process for approximately 48 hours. In order to observe the polarization effect within the time frame mentioned, the *"ON" Potential* reading results were taken periodically at 0-, 16-, 24-, 40-, and 48-hour intervals.

The representative polarization curves from the potential measurements taken at the Test Stations are displayed in Figure 6 below:

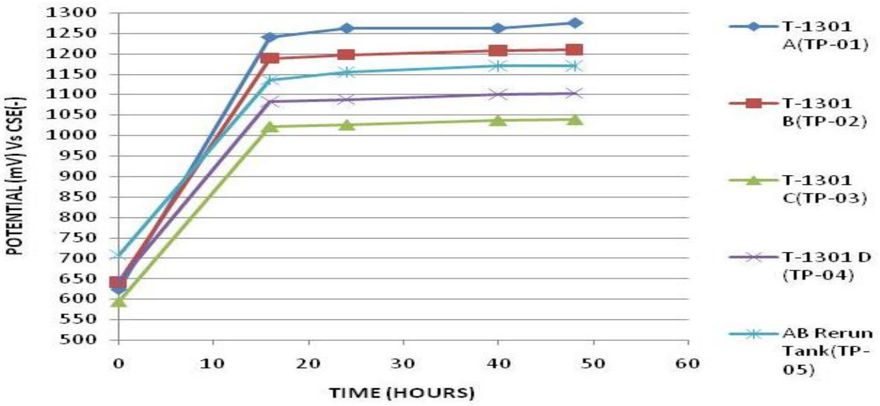


Figure 6 “ON” potential reading results [mV]

Based on Figure 6 above, the potential value for all structures would be enhanced significantly, since the transformer rectifier was already activated in advance of the 16 hours. At this time interval, the structure would be polarized to become more negative as an effect of the electron penetration on the respective structures. The potential of each structure would be decreased until it reached a protective potential (-850 mV) and it would become immune, as stated in the *pourbaix* diagram. The immune condition occurs when the potential of the structure stands below the corrosion potential (*Ekorr*) in the Brown Curve (Jones, 2005). After 48 hours, when the potential value is already seen as a stagnant condition, it can be considered that all of structures have already been perfectly polarized, and the process is called cathodic polarization. In order to obtain the true reading of the potential (*voltage drop free*), the transformer rectifier/current should be interrupted, using a current interrupter with intervals of 4 seconds “O*N”* and 1-second “*OFF”* criteria, in which the 1-second *“OFF”* criteria is defined as the true/*voltage drop free* potential reading. Thereafter, the value of polarization could be calculated as shown in Equation 4:

$$\text{Polarization} = \text{Instant Off Potential} - \text{Native Potential} \quad (4)$$

The representative final potential graphs from the potential reading results are displayed in Figure 7 and the quantitative data are as shown in Table 3.

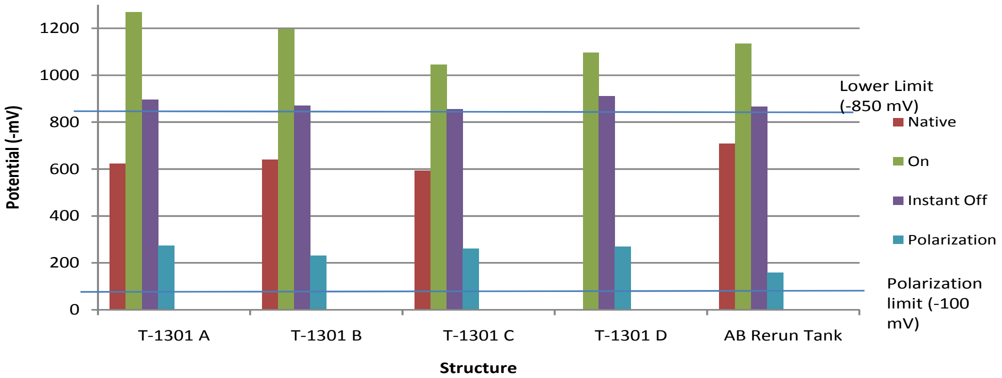


Figure 7 “ON and IR free” potential reading result [mV]

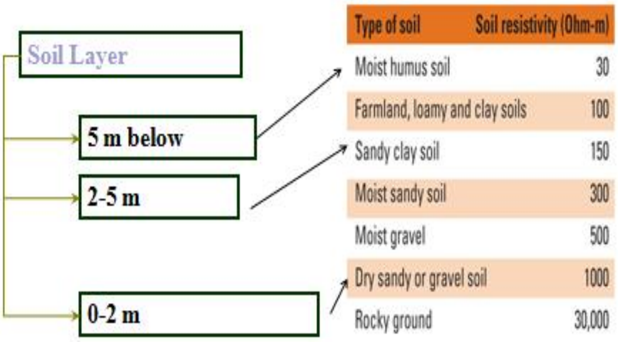
As per Figure 7 above, it can be seen that all of structures already stand on the minimum protection level (-850mV), furthermore, the minimum -100 mV polarization criteria also has been successfully achieved.

Table 3 Final potential reading results

No	Structures	Area	Structure to electrolyte potential reading (m V)				
			Natural	"On"	Instant "off"	Voltage drop	Polarization
1	T-1301 A	TP-01	-623	-1270	-897	373	-274
		North	-609	-1463	-887	576	-278
		South	-660	-1174	-1087	87	-427
		East	-604	-1270	-1011	259	-407
		West	-641	-1217	-936	281	-295
2	T-1301 B	TP-02	-641	-1197	-871	326	-230
		North	-632	-974	-946	28	-314
		South	-632	-1585	-875	710	-243
		East	-587	-1242	-1000	242	-413
		West	-631	-1124	-945	179	-314
3	T-1301 C	TP-03	-594	-1046	-855	191	-261
		North	-540	-948	-856	92	-316
		South	-646	-981	-874	107	-228
		East	-554	-942	-853	89	-299
		West	-579	-932	-889	43	-310
4	T-1301 D	TP-04	-641	-1096	-911	185	-270
		North	-633	-1340	-987	353	-354
		South	-632	-1218	-993	225	-361
		East	-621	-1453	-972	481	-351
		West	-636	-1251	-927	324	-291
5	AB-Rerun Tank	TP-05	-708	-1135	-867	268	-159
		North	-662	-1244	-883	361	-221
		South	-660	-1164	-864	300	-204
		East	-649	-1100	-883	217	-234
		West	-653	-1106	-875	231	-222

4. DISCUSSION

The general profiles of the soil layers of all tank structures at Company PT XX in East Borneo are typical, and has been shown in Figure 8 below:



Type of soil	Soil resistivity (Ohm-m)
Moist humus soil	30
Farmland, loamy and clay soils	100
Sandy clay soil	150
Moist sandy soil	300
Moist gravel	500
Dry sandy or gravel soil	1000
Rocky ground	30,000

Figure 8 General profile soil layer of aboveground storage tank at PT XX, East Borneo

Based on Figure 8 above, at the soil layer ranging from 0-2 meters deep, which has been defined as the sand layer, the sand is categorized as a high resistivity electrolyte, as per field data results. The soil resistivity result is high; therefore, it is not recommended for groundbed locations (Atkins et al., 2002). At the soil layer ranging from 2–5 meters deep and in accordance with requirements for a strengthened civil structure for an aboveground storage tank, this layer has to be filled with compacted soil, which contains a sand/clay soil type. This type of soil is still categorized as a high resistivity electrolyte, since it contains less ions or salt, which functions as a conductor path. For the next soil layer (below 5 meters), this layer has to be filled with humus or conductive ions for the current path. This type of soil is categorized as a low resistivity soil and is recommended for groundbed locations (Atkins et al., 2002). This is the reason why the anodes only would get placed in the depths below 5 meters, for at this depth, the maximum anode performance is expected to be obtained perfectly. Related to the above explanation, the potential mapping for all of the aboveground structures for the tanks is as shown below in Figure 9.

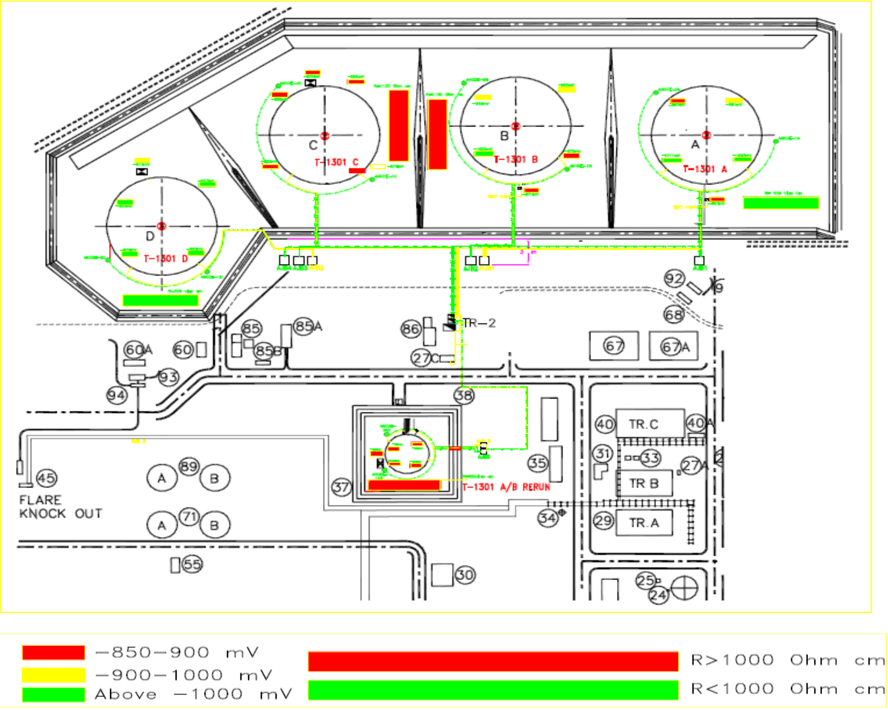


Figure 9 Potential mapping result of the aboveground storage tanks

There are anomaly conditions wherein not all of the sections of the structures received a uniform distribution potential. The lower value of the *instant "OFF" potential* was received by B, C, and AB Rerun Tanks. The performance of the distributed-anode configuration is constrained by the difference between the ohmic resistance from the anode to the periphery and from the anode to the center of the tank bottom (Atkins et al., 2002). Based on the soil resistivity results, the soil resistivity values around B, C, and AB Rerun Tanks are higher when compared to the another tanks, which is 1130 ohm-cm for the 9-meter depth. Soil with high resistivity normally contains less ions or conductive substances. This condition will cause the *instant "OFF" potential* reading to be lower than others, especially in regards to the ohm law, wherein the current has an inverse function in relation to the soil resistance. The higher soil resistance will create more barrier for current flowing into the tank structure (Lambert et al., 2008). Higher soil resistivity also will cause error readings, since we know that *"ON" Potential* value is the accumulative result of the true *"OFF" Potential* reading and the *voltage drop* as shown in Equation 5:

$$V\ \text{structure} = V\ \text{true} + \textit{voltage drop} \tag{5}$$

The voltage drop is defined as the voltage error, due to the additional ohmic resistance, which is caused by the environmental resistivity or the point to point distance measurement to the structure (Lambert et al., 2008). High soil resistivity will cause a higher *voltage drop* value. As shown in Figure 9 above, the average *voltage drop* value at B, C and AB Rerun Tanks are above -300 mV, which is the reason why the "*ON" Potential* value at B C, and AB Rerun tanks has been stated at very high levels. The O_2 content at soil layer has no effect on the potential distribution at the tank (Riemer & Orazem, 2005), The average values are still far away from the cathodic limit of -1.2 V (*copper/copper sulfate*), which is a point where hydrogen evolution is a significant concern (Riemer & Orazem, 2005). However, depletion of the oxygen content of the soil resulted in adequate levels of protection. The calculated range of potential on the entire tank bottom fell to readings between -0.85 V(*copper/copper sulfate*) and -1.2 V(*copper/copper sulfate*). The principal difference between the two cases is that for the depleted oxygen distribution, the potential distribution was much closer to being uniform and the entire tank bottom was protected. The uniform oxygen distribution case, corresponding to a newly-filled tank, clearly represents a worse-case scenario. It is easier to provide protection when the soil below the tank is depleted of oxygen (Riemer & Orazem, 2005).

The average pH value at the A and D tanks have a range in-between 4–7.4, whereas at C, D, and AB Rerun tanks, they have an average pH value above 8.2. The relationship between pH and corrosivity is about moisture content, cat-ion content, and an-ion content. As a conductor, the lower pH value with a range in-between 2–7 would cause more corrosive conditions (Telles et al., 2000). Hence, the corrosion rate would be enhanced. At a pH 7 value, the corrosion rate would be neutral, and for a pH value above the range of 7–8, the corrosion rate would be decreased. A lower pH value would make the soil resistivity lower and this condition would enhance current distribution from the anode to the structure (Kroon, 2005).

5. CONCLUSION

The key polymorphous cathodic protection upgrading design for corrosion control of steel tank bottoms in the oil and gas industry have been identified to be as follows: the current and voltage output demand to protect all of structures is defined as 154 Amperes and 40 Volts, respectively. Further results show that higher soil resistivity above 3000 ohm-cm will create disturbances for the current flowing from the anodes. This will cause a lower instance of *"OFF" Potential* readings. Hence, it means that higher soil resistivity above 3000 ohm-cm will cause e*rror* readings, especially in regard to the accumulation potential value between the true *"OFF" Potential* reading and the *voltage drop,* in which the *voltage drop* has a connectivity with environmental resistivity. In another study of the electrolyte mechanism influence, it was already found that lower pH 5–7 value was caused by lower resistance, which enhanced the rate of current distribution from the anodes to the structures.

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