Mitigate Corrosion Through Cathodic Protection of Steel Structures of Puma Energy in PNG

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Abstract

Prevention of Puma Energy facilities/structures in East and West New Britain Provinces of Papua New Guinea from corrosion has solely been based on sacrificial anodes. According to tests and data collected, it has proofed that sacrificial anodes cathodic protection (CP) system do not effectively protects the structures from corrosion. This was one of the main problems faced by Puma Energy PNG Limited across other CP terminals in Papua New Guinea. The sacrificial anodes system used by the company has ineffectively protected the structure due to its weak potential difference which solely emits from natural anodes (elements) without any external power supply source to effectively drive the current through. According to the research and study, the possible optimum replacement option is impressed current cathodic protection (ICCP). The impressed current cathodic protection system is one of the best methods of protecting and preserving steel structures from corrosion. The impressed system potential is reinforced by external power supply source where anodes potentials further pushes protective current supplied from rectifier units and drive through electrolyte which profoundly protected the structure.

Keywords
Anodes: Cathodes: Impressed current: Reference electrodes: Sacrificial anodes.

1. Introduction

The Rabaul and Kimbe Puma Energy terminals of cathodic protection system like others, have been through corrosion has the company immediately proposed for effective protective methods of corrosion prevention. Because Kimbe and Rabaul are both located near coast of Papua New Guinea, dissolved chloride and high humid have caused more damage to the steel structures when in contact with them. The cathodic protection theory was first introduced in 1824 by Sir Humphry Davy which was financed by the royal navy to investigate corrosion on ship hulls. The notion was quite tedious but with time and money, he has successfully convinced the society with the idea what is now known as cathodic protection system. He was assisted by his pupil Michael Freddy with their extensive research both on and offshore (Loto and Popoola, 2011).

The idea was impressed by the royal navy and without hesitation funded the research and project which ultimately become a successful notion which is now being introduced and practiced throughout the world by the modern era (Mohamed, Cahoon and Caley, 2012). The cathodic protection system includes sacrificial anode and impressed current protection using the existing electrochemical potential within the cathode and the anode. Potential differences between the anode and the cathode is the main difference that makes cathodic protection possible for the benefit of corrosion prevention in which the most negative elements are usually considered to be anode while more positive element is considered for cathode in electromotive force series.

Commonly used anodes in sacrificial anodes system includes Magnesium (Mg), Zinc (Zn) and Aluminum (Al) and its alloys for effective protection (Mohamed, 2015). More reactive elements in nature vigorously reacts with the environment and dissolved instead of cathode and in so doing, these elements are sacrificed to protect the cathode elements (steel Structures, pipelines and tanks) from corrosion. This is way it is known as sacrificial anode where the anodes are sacrificed and depleted in order to protect the cathode (Kioupis, 2019)

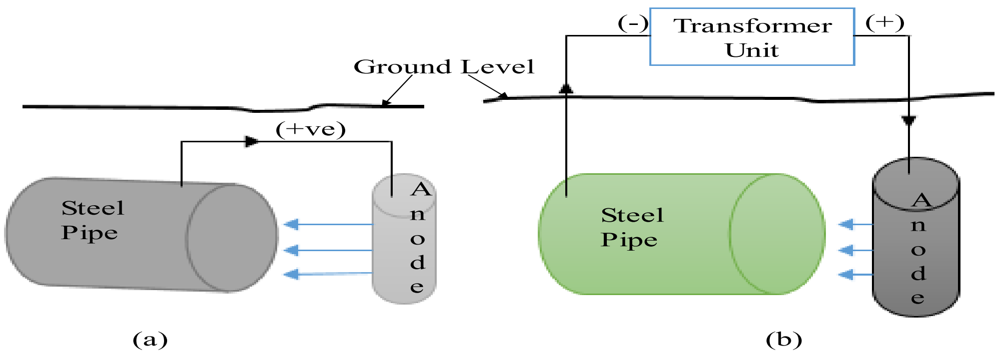

Figure 1. Cathodic protection by a galvanic (a) and impressed current (b) protection system (Francis, 2013).

2. Objective - Impressed Current Cathodic Protection (ICCP)

Impressed Current Cathode protection system is the terminology in which the external direct current (DC) power supply source is used to polarize the structure (Ashworth, 2010). The method comprises of power supply source from rectifier unit, junction box and connections are run through the electrolyte and into anodes and cathodes embedded beneath the electrolyte. This technique uses a lot of work and corrosion personal experts are frequently on site to ensure there is no power interruption which will profoundly affect the process and thus cost exceptional amount of funds to establish (Torrey, Little and Sears, 2020). The driving potential or voltage is induced from the direct current power source in which the corrosive electrons are forced out of the cathode (structure) and forced through the connection cables and deposited into the anodes adjacent to the embedded structures.

Impressed current method is necessary in cases where there is not enough current flow through the electrolyte from alternation power source and usually in bigger structure or facilities. It is used to supply positive electrons from the anodes to the cathode making anodes becomes negatively charges and cathodes becomes positively charged thus the structure is protected (Radwan *et al.*, 2017). The anodes are subject to sacrifice and corrode thus positive electrons from cathode is forced through when current is switch own through reference wires connected to the rectifier or junction box and into the cathode to polarize.

This is the optimum method where the corrosive electrons from cathodes are forced out and deposited into the anode where anodes will have oxidation reaction and corrode thereby protecting the cathode (structure). Consequently, protective electrons from the anodes are transferred or infiltrate through electrolyte only when there is low electrolytic resistant. Thus it is also necessary to ensure the electrolyte in which the structures are constructed needs to be monitored and ensure to be in compliance with efficient requirement and can be able to facilitate transfer of electrons is at its optimal stage. In that way, the structure is protected from corrosion as designated in Figure 2.

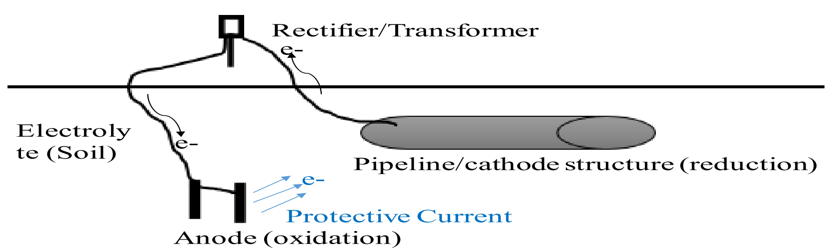

Figure 2. The transfer of electrons from cathode to anode during polarization

3. Literature Review - Sacrificial Anodes/Galvanic Protection

The sacrificial anodes or galvanic protection of cathodic protection is the method in which the cathode is protected by sacrificing anodes from its adjacent location. Sacrificial anodes terminology requires stringent rules from the electromotive forces series in which the most anodic or electronegative in nature is usually selected for anodes in cathodic protection system. Three most frequently chosen elements for sacrificial anodes are magnesium (Mg), zinc (Zn) and aluminum (Al) or alloys and composites of these metals (VanVlack, 2017). This is because, the naturally combining powers or potentials are much higher than preceding elements when descending from the electromotive force series. It naturally forces electrons through cables which connected from cathode to anodes to polarize the cathodes. The sacrificial anodes electrons are normally supplied through lead wires or cast-in wires connects from anode to cathodes (Ashworth, 2010).

As in impressed current method, reduction occurs on cathodes where there is loose of oxygen and oxidation is imminent on anode site where the oxygen ions are gained for oxidation reaction. Sacrificial anodes elements are commonly known to be most reactive and active element in nature where the driving force or potential is grater due to their combining powers normally found in group two and three of periodic table.

As per recent site visit to Puma Energy Lae terminal (PNG), most of facilities at the downstream processing plants used sacrificial anodes than impressed current. The service of sacrificial anodes on site were considered to be effective as observed and are up and running with regular feedback and reports on site. Puma Energy Lae terminal is entirely based on sacrificial anodes but no impressed current protection, however impressed current method is applied in Madang based terminal of Puma Energy in PNG for corrosion prevention.

Both offshore and onshore steel pipelines or tanks are protected from corrosion including ship hulls, high steel structure, building, bridges, ports, wharfs and jetties. The sacrificial anodes are more reliable than impressed current method because once the structure and anodes are installed, it continues to perform its normal process of protecting the structure by exchange of corrosive electrons such as (oxygen, carbon dioxide, hydroxide, and hydrogen sulfate etc.) from cathode and deposits into anodes through lead cable connections (E, 2006). The protective electrons such as hydrogen is then emitted through electrolyte from anode to cathode (structure) as designated in Figure 3.

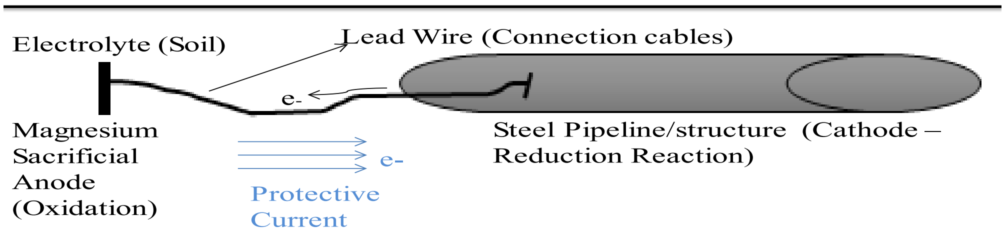

Figure 3. The ideology in which the corrosive electrons are forced into structure from magnesium anode.

Magnesium (sacrificial anode) Protected steel pipeline structure

$$Mg\ (s) \rightarrow Mg^{2+} + \ 2e^{-} \qquad\qquad Fe^{2+} + 2e^{-} \ \rightarrow Fe\ (s) \qquad (2)$$

Figure 3. Oxidation reaction (anode) Reduction reaction (cathode)

4. Methods and Results -Kimbe CP Site

Kimbe Puma Energy terminal also uses sacrificial anodes system to protect their steel facilities from corrosion. The storage tanks and unground pipelines included submerged structures are all protected by sacrificial anodes or galvanic system. Because of its simplicity and economically viable and portable use of reference electrodes, company has been accustomed to this system throughout its countries main oil and tanks facilities. Other reason being that the structures constructed on site were not huge and complicated though chloride content and dissolved oxygen ions are more rapid and abundant in nature in coastline of Papua New Guinea.

The raw data collected as designated on Table 1 were from 17/08/2017 to 17/08/2019. However further data have been collected through to 2020.

Table 1. Copper/Copper sulfate ($CuSO_4$) and Silver/Silver chloride (Ag/AgCl) reference electrodes. Protected (P), Unprotected (UP)

Sites/Time	Aug, 17, 16		March, 9,17		Aug, 17, 17		March, 09,18		Aug, 17, 18		March, 09, 19	
RE	$CuSO_4$		$CuSO_4$		$CuSO_4$		$CuSO_4$		$CuSO_4$		$CuSO_4$	
P/UP	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
SL	-430	-1202	-400	-1202	-439	-1217	-474	-1203	-412	1153	-459	-1162
TF	-343	-1291	-420	-1291	-416	-1203	-440	-1180	-402	1142	-407	-1111
T55	-473	-1377	-395	-1377	-421	-1185	-474	-1203	-463	1261	-465	-1239
TK9	-389	-1241	-415	-1378	-424	-1242	-500	-1275	-473	1232	-528	-1240
T55P	-521	-1378	-406	-1241	-423	-1188	-440	-1180	-420	1178	-401	-1107
T55	-379	-1241	-364	-1321	-424	-1242	-394	-1235	-414	1215	-401	-1173
TL	-287	-1321	-400	-1321	-467	-1255	-490	-1228	-465	1206	-499	-1004
TLT	-381	-1241	-360	-1241	-438	-1226	-396	-1135	-414	1155	-399	-1106
RE	$CuSO_4$		$CuSO_4$		$CuSO_4$		$CuSO_4$		$CuSO_4$		$CuSO_4$	
CW	-357	-645	-300	1200	-406	-1354	-327	-1318	-327	-1318	-248	-1149
RE	AgCl		AgCl		AgCl		AgCl		AgCl		AgCl	
EF	-316	-555	-316	-555	-419	-1287	-548	-1258	-452	1021	-384	-1230

Note: TF= Tank farm, T55 = Tank55, TK9 = Tank 9, T55P = Tank55 Pump, TL = Transfer Line, TLT = Transfer Line on Tank, EF = East Flange

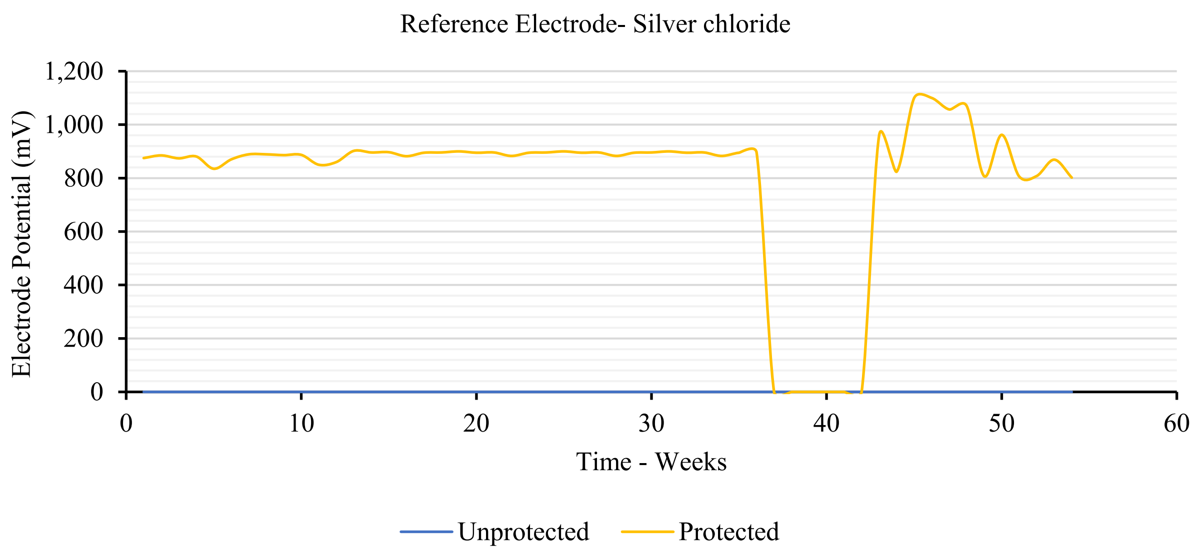

Figure 4. Kimbe sacrificial anodes protection system.

As per Figure 4, there is a major decline in unprotected structures. This is possibly due to failed cathodic protection performance or considered nil instillation of CP system to the structure. Other possible reasons could be weakening voltage from anodes to cathode and as such, the system is greatly affected and considered failed and declining CP as in accordance with Australian standards CP system. Sacrificial anodes installed in various parts of the country in Puma Energy terminals have been drastically undermined and superseded by corrosion. From Figure 4, though cathodic protection has been supplied through sacrificial anodes system, it still corrodes. Weakening voltage supply from anodes have greatly affected the system and has suffered corrosion attacked consistently. This is one of the problems needed to be solved by Puma Energy through recommendation and instillation of impressed current cathodic protection system.

Protected structure of sacrificial anodes were considered to have provided fair protection (Figure 4) in accordance with standards and regulations but suffered major damage to portion of the structure. This is also due to failed sacrificial anodes or weakening anodes and stray current.

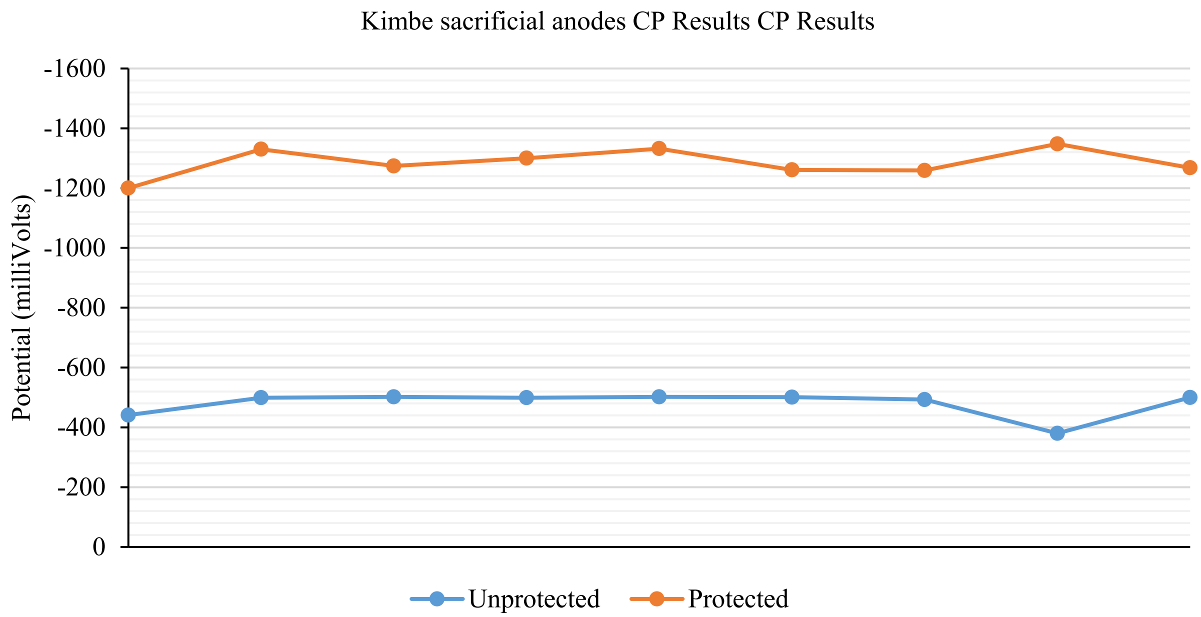

Figure 5. Results of sacrificial anodes CP to Puma Energy Steel facilities in Kimbe.

The level of protection rendered from sacrificial anodes to steel facilities in Puma has gone below standards and specification. As demonstrated from Figure 5, protected portion of the structure exceeds standard specifications and compliance guidelines and regulations. The values need to be limited to (-850 mV to -880 mV) for effective protection which is the standard per AS2832.1.2015 where in this case gone way above values expected of a sacrificial anode CP system. In fact, the values resemble that of impressed current method though sacrificial anodes system has been installed.

The structure is defected by various foreign materials or possibly due to stray current. It may also cause from soil resistivity (electrolyte) but because of continuous supply of potential, it has gone excessively in less resistive area. However, most possible cause of decline in CP system is from weak supply of potential from anodes to cathode via electrode. Because the sacrificial anodes system does not adequately supply its impressive electrons due to no external power source to boost the existing potential, the current becomes weak and dissolved into the electrolyte before reaching cathode. As such, the power of electrons from anodes to cathode becomes dull and system no longer performs its designated task. Thus, the facilities were not protected effectively as demonstrated on Figure 5 and 6.

The cathodic protection engineer needs to visit the sacrificial anodes to ensure the facilities are protected effectively by the system. Furthermore, recommendation is to be sought for possible inspection and associated rectification procedure where in this case, it requires impressive current method in place of sacrificial anodes for this declining CP. Currently, it is confirmed by the raw data collected that facilities are not functioning in accordance with Australian standards and specifications.

5. Rabaul CP Site

Table 2 shows the results obtained from Rabaul Puma Energy terminal from 28/04/2016 to 28/04/2018. Silver chloride and copper sulfate solutions have been used as portable reference electrodes to obtain raw data for analysis and evaluation as indicated. However, further data have been retrieved through to 2020.

Table 2. Silver/Silver Chloride (Ag/AgCl) and Copper/Copper Sulfate ($Cu/CuSO_4$) reference electrodes (RE) of protected (P) and unprotected (UP).

Sites/Date	Apr,28,16	Nov,03,16	Apr,28,17	Oct,28,17	Feb,14,18	Aug,11,18
RE	Ag/AgCl	Ag/AgCl	Ag/AgCl	Ag/AgCl	Ag/AgCl	Ag/AgCl

P/UP	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
WE	-683	-1567	-334	-1247	-334	-1247	-590	-1445	-590	-1680	-572	-1577
RE	$Cu/CuSO_4$		$Cu/CuSO_4$		$Cu/CuSO_4$		$Cu/CuSO_4$		$Cu/CuSO_4$		$Cu/CuSO_4$	
P/UP	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
TE	-620	-1655	-621	-1669	429	1440	-632	-1608	-632	-1445	-570	-1624

Note;WE = Wharfend, TE = Terminal End

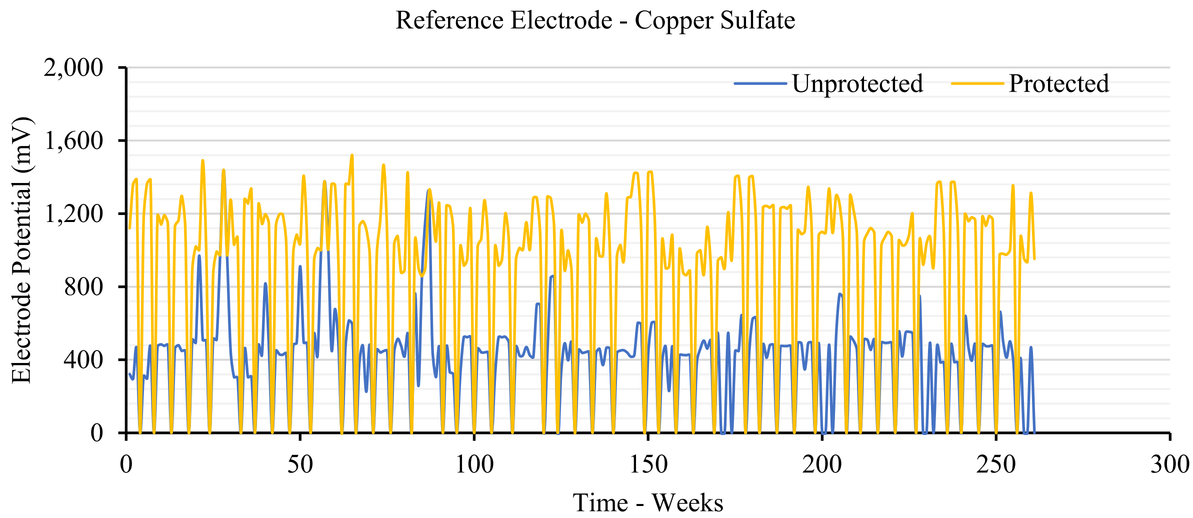

Figure 6. Representing Rabaul Sacrificial Anode CP system

There is a fluctuation on both protected and unprotected pipelines. It is vividly revealed that the level of protection given to the structure by sacrificial anodes do not maintained consistency and thus result to possible corrosion on sections of the pipelines. Furthermore, it can be concluded that there is an inconsistency due to stray current and impedance. This may be possibly because of weak potential supplied by the installed anodes which disappeared in resistive electrolyte.

Even the protected structures have been attached as denoted by the orange line which reach even way below the -200 millivolts which is considered failure by Australian standards and specification. The reason is again the poor arrangement of anodes or possibly reduction in potential supply due to overpowered by the magnitude of structures the anodes connected to. More amount of structures connected to the same anodes would mean that the sufficient energy provided to transfer impressive or protective current is minimized and thus weak and lost along its way. This will result in anodes consumed so quickly without proper cathodic protection.

6. Conclusion

According to the data and graphs, it has been noted that both Rabaul and Kimbe CP sites of PNG Puma Energy facilities have been drastically reduced in cathodic protection. The sacrificial anodes potential has been limited and did not functions adequately and thus considered weak and fail as per international CP standard regulations AS2832.1.2015. It has been in dare need of recommendation for possible replacement option. This replacement option is impressed current where in larger structures or numerous quantities of structures, the only reliable techniques use to protect the structure with sufficient and adequate protection and thus its powered by external power supply source that continues to reinforce its potential which is the main advantage.

The Puma Energy throughout the country require urgent intervention to phase-lift the sacrificial anodes to impressed current method. The sacrificial anodes cathodic protection method used throughout all centers have found to have been weak and declining due to a lot of structures attached to certain anodes which overpowers their potential to drive the impressive/protective current from anode to cathode via electrolyte. Plenty of structures connected have weaken the system and thus resulted to poor CP system faced in Puma Energy across PNG terminals.

According to the Australian standards and specification regulations AS28321.1.2015, the CP protection criteria has not been met by the sacrificial anodes CP. The facilities were vastly undermined by corrosion and exceeds the protection power rendered by sacrificial anodes system. The Puma Energy facilities do not have sufficient potential and strength to prevent corrosion in compliance with standard manuals as indicated by various graphs in conjunction with the explanation. As also reported from Puma Energy contractors, the facilities need immediate facelift to more reliable standards which perform reliably to protect the structure for possible corrosion deterioration. The only way to mitigate and safe failing CP system in Puma Energy is by replacing sacrificial anodes with impressed current for the benefit of facilities.

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