Selecting Appropriate Cathodic Protection Criteria for Tank Bottom Using Polarization Method

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Summary

Cathodic protection is one of the most applicable corrosion control method in industry. Protection criterion are key factor in this method. Based on the latest revision of ISO, DIN, EN, NACE and other recognized international standards and specifications, -850 mV w.r.t CSE and 100 mV shift with some consideration are utilized for protection criteria. In this project (South Pars Gas Field Development, Persian Gulf), 5 of 7 tank bottom plates are protected by cathodic protection method with negative 850 mV criteria successfully. Close interval survey around two other tanks showed current leakage. In this case, achieving the negative 850 mV criteria needs higher level of protection current which increases current leakage, unpredicted damage in nearby structure and earthing system and may produce gasses that depolarized the protected surface besides reducing working life of the equipment and materials.
An integrated system consisting transformer rectifier control unit and a potential measuring system is developed to extract polarization behavior of the mentioned tank bottom plat in contact with soil. Analysis of polarization diagrams show that 100 mV shift meet the requirements of the cathodic protection criteria for the two current leaking tanks. It decreases corrosion rate by more than 10 times along with efficient current leakage and depolarizing gases production reduction.

1 Introduction

There are different industrial methods for corrosion protection such as selecting appropriate materials, chemical modification of environments, separating the protected surface from the environment, shape and structural modification and reducing the tendency of corrosion. The last one is done by supplying the needed electrons for cathodic polarization which considered as cathodic protection. In many cases, such as tank bottom plate in contact with soil, cathodic protection is the most effective and common corrosion control technique.
One of the best known early definitions of cathodic protection was offered by Mears and Brown in 1938 as a method in which cathodes are polarized to the open circuit potentials of the local anodes [1]. Another referenced definition was presented by Shreir. Based on Shreir description, in cathodic protection electrons of electrochemical corrosion reactions, anodic and cathodic reaction electrons that paths through metals, supplied by external source, so the common corrosion reactions halted [2]. New technical texts, standards and handbooks defined cathodic protection as a technique to reduce the corrosion rate by polarizing entire protected surface to cathode.
The key factor in cathodic protection is protection criterion. Selecting between different criterion and their pre-requisitions is the CP engineer‘s decision that will affect the quality of the long life performance of the protected system. In some cases, such as the presented tanks, selecting an appropriate criteria needs to know the scientific background of the protection criterion. Protection criterion will be mentioned in the following section.

In this paper, utilizing polarization method and considering side effects of each criteria, the best cathodic protection criteria is recommended in the mentioned situation.

2 Tank Bottom Cathodic Protection Criterion

EN 13636 addressed EN 12954 as a reference for the CP criteria [3, 4]. EN recommend negative 850 mV vs Copper/Saturated Copper Sulphate Reference Electrode (CSE) protection potential (when free corrosion potential is between -650 to -400 mV vs CSE) or any confirmed sound engineering practice that reduces the corrosion rate to less than 0.01 mm per year. Moreover, for aerated sandy soil the criteria reduces to -750 and -650 mV vs CSE for soil resistivity between 100-1000 ohm.m and more than 1000 ohm.m respectively. It means lower polarization is acceptable in high resistance environment. In addition, the standard predicts the natural potential will be reduced in high resistance environment too. DIN 30676 has the same structure with little different boundary in high resistivity environments [5]. Nevertheless, the DIN 50676 is withdrawn and is not valid anymore.

NACE RP-0193 and NACE SP-0285 recommend three criterion, -850 mV vs CSE potential, negative 850 mv CSE polarization potential and 100 mV polarization shift as protection criteria of tanks bottom, in the absence of data that confirmed reducing the corrosion rate sufficiently by CP [6, 7]. ISO 15589-1 which could be used for tank bottom, considers both polarization to -850 mV vs CSE and 100 polarization shift as two known protection criteria [8].

NACE SP-0186 which is applicable for well casing, proposed another method to extract protection criteria for a cathodic protection system. In this method, polarization behaviour of a protected surfaces is analysed by E-Logi diagrams [9].

3 Protection Criterion Analysis

Criterions that have absolute value, such as -850, -750 and -650 mV CSE, are based on thermodynamical analysis while 100 mV shift is a kinetical criteria. Beavers and Garrity in chapter 4 of Peabody book [10] compare these two methods. In the defined condition, aerobic soil with a specified temperature, there is not any anodic site on surface of steel in soil contact with potential more negative than -850 mV vs CSE. Therefore, when the steel surface polarized to -850, the whole surface could be cathode respect to the external anode. It means that applying a CP to achieve potential more negative than -850 mv vs CSE, causes the nature of the surface to reach beyond the thermodynamical boundary of corrosion so there is not any tendency to corrosion.

As Beavers clarified [10], the slop of anodic reaction, anodic Tafel slope, has a value of ~100 mV per decade of current density. It means, each 100 mV polarization will reduce corrosion by a factor of 10. Somehow, polarization concept is used in NACE SP-0186 for well casing corrosion protection by cathodic protection [9].

4 Studied Systems

Seven tanks bottom are studied in this research. All the tanks are established in South Pars Gas Field Development in north of Persian Gulf, Iran. After mechanical completing, transformer rectifier (TR) units are energized and the protection potentials are measured in respect to the permanent CSE.

Considering following assumptions, section 4.2, current analysis is done to extract protection current. Two tanks showed unusual protection current. In the next step, Close Interval Potential Survey (CIPS) around the two tanks is applied to find out any current leakage to the surrounded structures. Synchronized current interrupting and off-potential recording is utilized to extract polarization diagram (E-Logi) for interpreting electrochemical behaviour of the tank bottom plate.

4.1 Tanks Construction

There is 100 cm fine sand below the bottom plates and a high resistant Geo-Membrane over a concrete foundation. Between tank bottom plate and Geo-Membrane, anode grid, consisting MMO ribbon anode and Ti conductor bar, is installed 60 cm beneath the bottom plate. In depth of 30 cm, permanent CSE reference electrode(s) are installed before the mechanical completion of tank bottom. All bottom plates surface in contact with sand are coated by epoxy with 400 µm thickness before welding so normally 50% of surface could be considered bare and the rest as a well coated. The resistivity of the sand is around 20,000 ohm.cm.

4.2 Protection Current Analysis

In protection current density analysis, the following assumptions are considered:

- The construction procedures, coating and installation sequence, of all 7 tanks were identical so all assumptions are same in this study.
- 25% increase in current density for each 10ºC increase in operating temperature, as ISO 15589-1 described [8].
- 50% of the bottom plate is bare and all the protection current is used for this part and the consumed current in the rest of the system, the coated part, is negligible.

Table 1: Protection Current Analysis

Tag.	Dia. (m)	Opt. Temp. (°C)	TR Current (A)	TR Voltage (V)	Current Density with Temp. Mod. (mA/m²)	On Pot. (mV vs CSE)	Off Pot. (mV vs CSE)
TK1	6.2	40	0.5	4.2	26.5	-1576	-880
TK2	6.2	80	0.4	5.5	11.8	-3255	-912
TK3	10.2	30	0.9	5.5	22.0	-2271 -2208 -2285	-959 -973 -940
TK4	12.2	70	1.6	3.2	13.7	-1985 -1790 -1820 -1863 -1970	-920 -880 -880 -950 -930
TK5	36.9	45	17	8	23.1	-1693 -1515 -1497 -1513 -1535 -1786 -1860 -1852	-850 -920 -845 -875 -905 -833 -877 -945

Tag.	Dia. (m)	Opt. Temp. (°C)	TR Current (A)	TR Voltage (V)	Current Density with Temp. Mod. (mA/m²)	On Pot. (mV vs CSE)	Off Pot. (mV vs CSE)
TK6	24.9	50	22	7	60.2	-1856 -1754 -1759 -1873 -1805 -1736	-853 -843 -770 -818 -827 -741
TK7	24.9	50	23.2	7.2	63.5	-1844 -1803 -1782 -1819 -1807 -1977	-811 -825 -820 -830 -901 -831

4.3 CIPS around the Two Tanks

As mentioned above, two last tanks, TK6 and TK7, showed unusual protection current density such that the CIPS was utilized to check any current leakage to the surrounded structure. One CSE kept 0.5 m away from the tank and the portable reference electrode moved upward the tank shell as presented in figure 1. To increase the accuracy, potential reading was done in both on and off state.

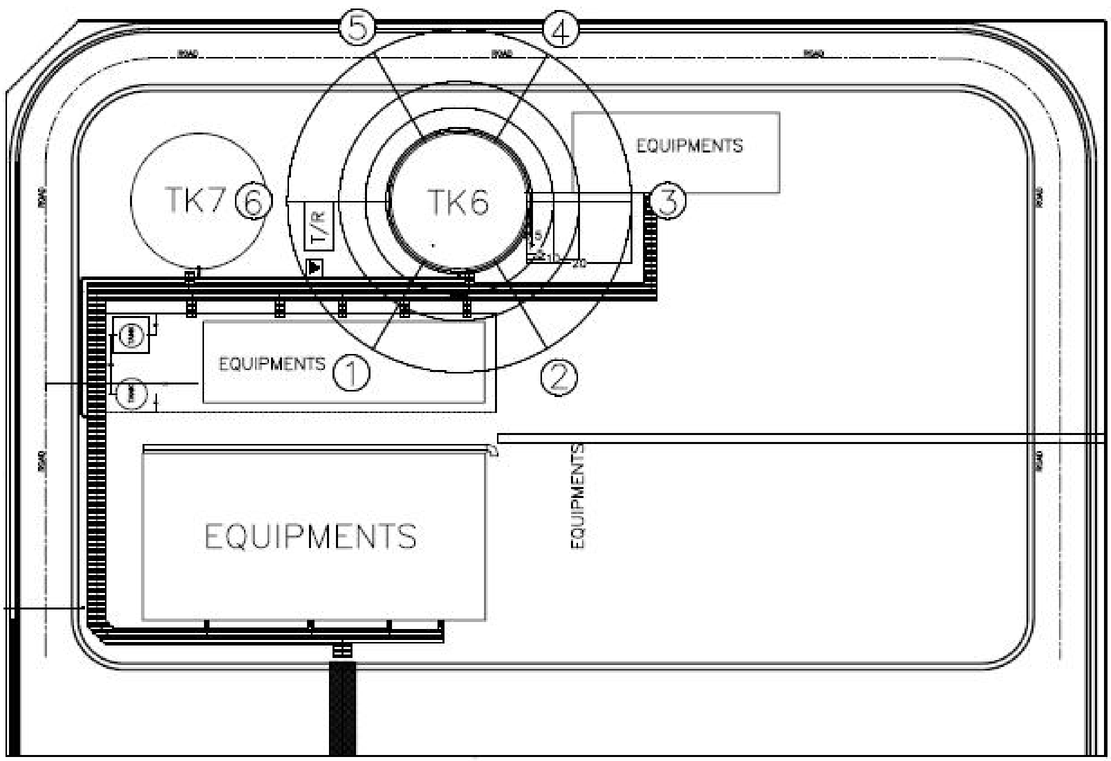

Figure 1: CIPS Map around TK6

Table 2: CIPS around TK6

Measurement Direction	Condition	CIPS Measurement Cell to Cell Potential (mV)				
		0.5 meter	1 meter	5 meter	10 meter	20 meter
1	On	-188	-227	-290	-316	-209
	Off	-109	-6	-9	-36	-51
2	On	-102	-152	-213	-109	-192
	Off	-9	+16	-14	-71	-5
3	On	-211	-243	-272	-311	-401
	Off	-16	-70	-58	-92	-198
4	On	-309	-320	-352	-324	-318
	Off	-63	-61	-80	-64	-59
5	On	-47	-67	-91	-84	-55
	Off	+43	+55	+63	+81	-104
6	On	-293	-324	-358	-334	-306
	Off	-43	-47	-52	-34	-23

4.4 Polarization Behaviour of Tank Bottom Plate

E-Logi diagrams (Polarization diagram) of both tank bottom plate is extracted through interrupting the TR and reading the polarized potential simultaneously, according to NACE SP-0186 [9], developed by Borna Electronics Company. Time interval between each switching/reading was 1 hour until the potential reached to steady state (changes is less than 5 mV).

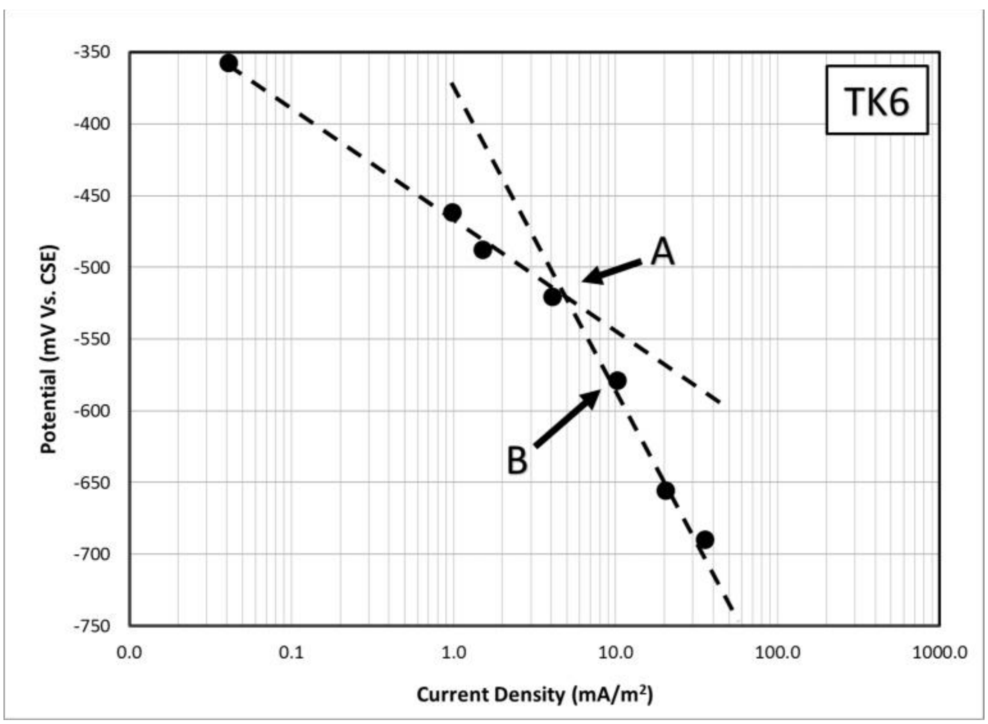

Figure 2: Polarization Diagram (E-Logi) of TK6

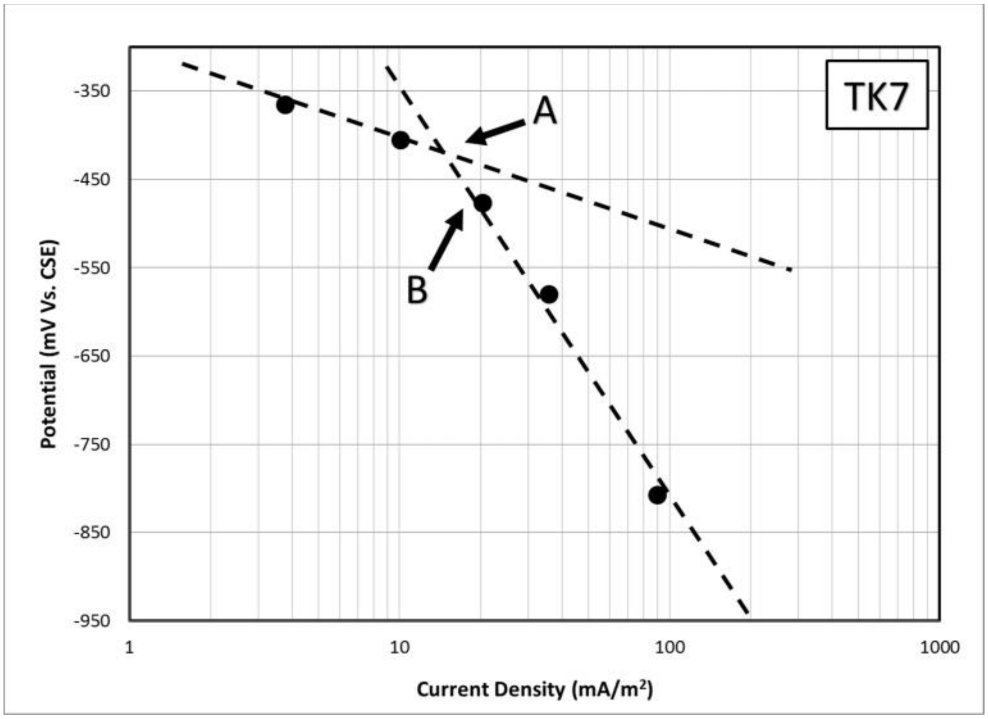

Figure 3: Polarization Diagram (E-Logi) of TK7

5 Discussion and Conclusion

In technical publications [9, 11] different analysis are done in E-Logi diagrams. In some cases, intersected points, point A in figures 2 and 3, are considered as the sufficient protection level. However in some cases first point of Tafel segment, point B in figure 2 and 3, has been selected as the appropriate point for corrosion protection. In our case, considering the first point (A), it could be understood that the 100 mV shift criteria, recommended by EN, ISO and NACE standards, has been successfully achieved [12]. Moreover, the measurements showed that applying this criteria has the lowest current leakage and gradient in CIPS test.

Figure 2 and 3 show that increasing polarization will change the state of reaction from activation control to diffusion control. This is a key parameter that confirms the more polarization will increase gas production in anode, consequently depolarized the cathode. The unnecessary high polarization, -850 mV, produces more gas and depolarize the surface and increase current leakage. This could be a hysteresis loop that will destroy the cathodic protection system in long services. If point B is considered as a criteria, toughest state, the -750 mV vs CSE could be considered as protection criteria and no need to reach -850 mV polarization. This result is in comply with the EN 12954 for high resistance environment too [4].

Finally, more polarization is not the best way for corrosion control and the -850 mV polarization is not recommended for any CPS.

6 References

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