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Design Considerations for Complex Plant Cathodic Protection System

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ABSTRACT

Designing of cathodic protection (CP) systems for buried structure in a complex hydro carbon plant is challenging due to de-similar metals, different type of coating systems and bare grounding systems. The cathodic protection design for the all buried structure must be integrated. To avoid interference the design should take into consideration the bond for all the structure.

This paper looks at various scenarios for CP where buried structures for complex plant, and the type of survey to be performed, data collection and analysis of survey data for the design. The present paper answers to questions such as the need for an intergraded CP system for all the buried structures and grounding systems, different type of CP systems for plant, shielding effects and protection criteria.

1. INTRODUCTION

Designing of the cathodic protection (CP) system for a buried underground metallic structures in existing or new plant is very challenging due to dissimilar metals like Carbon steel, stainless steel and bare copper grounding system.

There is a requirement for proper survey of the existing cathodic protection system in the existing plant for creating a suitable design. It need not to be emphasized that a person having broad experience in cathodic protection surveys is essential. For an integrated and effective cathodic protection system the new structures with good coating must be bonded to existing buried structures having comparatively poor coating or bare.

The new plant design required to study all the structures before designing cathodic protection systems.

2. DESIGN APPROACH

The design for a plant cathodic protection system must be prepared based on the following approach:

- ✓ Project specifications.
- ✓ Client's standards and referenced international standards.
- ✓ Underground metallic structures drawings, Hazardous area layout and AC power details.
- ✓ Site survey.
- ✓ Survey results.

For engineering economy, there should be a consideration of the existing CP stations along with the available power sources, and anode beds having spare capacity, in existing plant, that may have the possibility to be utilized to protect the new structures. To avoid interference, the new structures must be bonded with existing nearest buried structures.

3. SITE SURVEY

A study of buried metallic structures' drawings is very important for a detailed survey of the plant. Lists need to be prepared for the required site data to be collected during the survey. Following is the minimum data required to design the cathodic protection system.

- ✓ Pipe to soil potential at nearest existing buried structure
- ✓ Existing cathodic protection station locations, rated and operating parameters (in case of existing plant)
- ✓ Potential gradient of existing anode (selected locations)
- ✓ Soil resistivity at proposed anodes location and depth (Note: Existing Anode bed must be in OFF condition during the soil resistivity measurement, in case of existing plant).
- ✓ Potential gradient test at new plant location.
- ✓ Current requirement survey in case of existing plant.

3.1 <u>Soil Resistivity & Ground Conditions</u>

In accordance to mandatory requirements, the detailed soil resistivity survey should be carried out with complete details of following and measurements should be recorded and analyzed;

a) Date of Measurement.
b) Instrument & Method used for Testing.
c) Name of Engineer/Technician and qualification to perform the survey.
d) Soil Analysis like pH, chlorides, sulfides and anaerobic conditions.
e) Ground Conditions like paved and non-paved locations.
f) Weather Conditions like temperature & humidity.
g) Other Particular Remarks or Findings.

In most cases the soil conditions in plant facilities are almost homogeneous, therefore average soil resistivity value can be assumed for design calculation but It is recommended to take resistivity for each anode location for perfect design.

3.2 Structure & Facility Details

Generally buried structure and facility information available with plant owner or consultants for new plants. Even then, it is important that the provided feedback shall be verified during survey, because there might be some changes, updates, incidental structures or particular information which is being over looked but important as CP point of view.

Electrical isolation of those structures which are being under the consideration of CP protection from other structures like above-grade structures, metallic supports and common grounding system etc. should be confirmed and verified since it is the main thing for deciding which type of CP system should be provided.

3.3 Current Requirement Survey for Existing Plant

The current requirement survey is the best choice for estimate the current requirement in existing plant. It is difficult to calculate the current required by theoretical for existing plant. The survey requirement is to inject current into the earth at the site where the permanent cathodic protection system will be proposed. For a giant structure, a sample area can be selected for the initial test phase. A suitable temporary power supply (test rectifier) to be connected between the structure and test anode bed. Test current is applied between the anode bed and the structure and the effects on the structure are measured. A controlled amount of current can be applied to the structure from the anode. Please refer Figure - 1 for survey arrangement. The electrochemical potential between the structure and the reference electrode and an "IR drop" produced between the points in the electrolyte where the reference electrode is located to be measured.

If it is possible the temporary anodes like ground rods will be installed in plant and curry out same time for whole plant.

$$\mathrm{I}_{req} = \frac{\Delta E_{\mathrm{preq}} \mathrm{x}\, I_{\mathrm{test}}}{\Delta E_{\mathrm{ptest}}}$$

I_{req} = Estimated current requirement (A)
ΔE_{ptest}= Polarization from test (V) [$\Delta E_{OFF} - \Delta E_{initial}$]
ΔE_{preq}= Polarization required (V)
= [0.850 V – ΔE_{OFF}] for -850 mVCSE polarized potential criterion or [100 mV] for 100 mV polarization criterion

4. DESIGN CONSIDERATIONS

In all cases, implementing cathodic protection with galvanic system or impressed current with "remote ground-bed" method or impressed current with "earth potential rise" method; following are the consideration before designing the system.

4.1 Protection Criteria

Generally owner companies either adopting protection criteria from international standards or developing by their own through investigations, experiments and historical results. Therefore it is important to know about the criteria to be followed.

There are other variables as well, which involved in selection of protection criteria, that is;

a) Temperature of Structure.
b) Anaerobic Conditions in Environment.
c) Concentration Cells Development in Environment.
d) Inter-Connected Dissimilar Metals.

4.2 Current Density

Again this variable, which is most important and basic for designing are either adopting through international standards, literatures and researches or developed by their own through investigations, experiments and historical results.

There are other variables as well, which involved in consideration of current density application and current requirement calculations;

a) Coated & Bare Area of Structure.
b) Electrical Isolation of Structure.
c) Temperature of Structure.

4.3 System Design Life

The required system life of a designed cathodic protection system is not a variable which directly contributing in designing, but it is a reference based on structure design life requirements. Therefore this information is not available in industry standards, and generally referenced from project specifications or through collect technical requirement process. In the Middle East 20 years design life are used by oil producing companies.

5. DESIGN METHODOLOGIES

The above discussed considerations are keys for the designing cathodic protection systems in plant facilities. Here below, some possible methodologies are being discussed, which specifies the ways for designing cathodic protection system in process plant facilities.

5.1 Galvanic Cathodic Protection System

The galvanic cathodic protection system is the most economical way of CP protection for structure but with lots of limitations, therefore in process plant facilities, rarely being used. The application of this method is applicable as following;

1) The current requirement of structure is low.
2) The electrical isolation of structures is possible.
3) No nearby existing or incidental structures.

This system is working when a high potential electrode like Magnesium, Zinc or Aluminum is connected to the structure through a metallic path. This develops a galvanic effect between two electrode (anode and structure) and drives current due to potential difference between them. Anode starts consume and protect structure until its potential comes in equilibrium.

In designing of CP with galvanic anodes, the main and basic requirement is to calculate the structure current requirement. Generally based on theoretical calculations the required anode quantities will always come very less, but practically there should be a consideration for environmental changes and seasonal effects like dew, rains, temperature change, natural heterogeneity and fluctuation in ground water levels causing variation in soil resistivity. Therefore the proposed anodes quantities should always be higher than the designed depending on expert judgments and past experiences in similar areas.

This is very important and always preferable that the galvanic anodes should be connected to structure through a test station as a CP monitoring facility, because it gives the following provisions;

1) It connects or disconnects galvanic anodes depending on future requirements.
2) More anodes can be added to the system without making addition cable connection to pipelines, which saves from lot of civil / mechanical / electrical activities and pipeline coating damages.
3) It also gives the provision to control and monitor the driving current by adding resistance in circuit.
4) It also provides provision to install permanent reference electrodes, coupons and probes for effective monitoring purpose.

5.2 <u>Impressed Current Cathodic Protection System With Remote Groundbed</u>

This is a common and widely used ICCP method in combination with different remote groundbed system like surface horizontal groundbed system, surface vertical groundbed system and deep well groundbed system. All these groundbed systems are dependent to specific conditions and requirements. The common thing is that all these systems used there, where structure current requirement for protection is large and finite which can be calculate or determined through test. Following are some scenarios in which this method is applicable;

1) The electrical isolation of structures is possible.
2) The current requirement of structure can be calculated or determined through test.
3) The CP current can reachable to all structure surfaces without any shielding.

In designing of ICCP with remote ground beds system, the main and basic requirement is to calculate the structure current requirement with consideration of all factors may contribute in additional current requirement like;

1) Coating damages during structure installation.
2) Coating degradation with passage of time.
3) Bonding with other existing structures.
4) Factors affecting current density.

Generally ICCP system with remote groundbed system is commercially economical in comparison with ICCP system with distributed or linear anodes and less effective way for plant piping protection since the desirable condition for remote groundbed system cannot achievable in plants.

5.3 Impressed Current Cathodic Protection System With Distributed Groundbed

The requirement of impressed current cathodic protection system with distributed groundbed is there, where structure current requirement for protection is extremely large or infinite, presence dissimilar metals and if the requirement is for hot spot protection. Generally these situations are significantly observed in plant areas. Following are some examples of such scenarios;

1) The electrical isolation of structures is not possible due to safety issues.
2) Uniform current distribution is not possible from remote groundbed due to structure complications.
3) Shielding of CP current due to underground incidental structures, like concrete foundation, pits, channels etc.
4) Interconnected dissimilar metals like copper groundings.
5) Un-protected section of structures, where CP current cannot reach.
6) Metallic section of non-metallic piping system.

The phenomenon of distributed groundbed system is based on “earth rise potential” method, in which anodes placed in evenly distribution close to the structure. This arrangement gives the CP current path from anode to the structure up to certain length, which is directly under the influence of anode gradient. This certain section of structure polarized with respect to earth potential under the anode gradient. Where the limit of this particular section polarization ends next anode influence started. In this way anodes evenly distributed around the structure and an effective uniform current distribution can achieve along the complete length of structure. Therefore, it is very important that what should be the anode-to-structure and anode-to-anode distance.

In designing of ICCP with distributed groundbeds, the main and basic requirement is to calculate the distances of anode-to-structure and anode-to-anode which gives sufficient polarization over structure that can be maintained within the protection criteria. Refer Figure - 2 which shows the arrangement of anode distribution over structure.

On pipeline surface “P1” is point just in front of an anode “A1” and “P2” is at midpoint in between of two successive anodes “A1 & A2”. First at point P1, the potential rise is calculated by the effect of both anodes, similarly at point P2, again potential rise is calculated by the effect of both anodes. The difference of structure potential at “P1 & P2” location should be almost same (as ideal) or at least less than 100mV difference. The concept of 100mV difference is assumed, considering the phenomenon of 100mV polarization shift at which all local developed galvanic cells on structure minimized to acceptable limit. Following is equation which is used to calculate the potential rise over structure;

$$\Delta V_X = \frac{0.5 \times I_A \times \rho}{\pi \times L_A}\left(\ln \frac{\sqrt{L_A{}^2 + X^2} + L_A}{X} \right)$$

Where:

ΔV_X = Earth potential change at distance “X” from the anode (V).
I_A= Current flow from the anode (A)
ρ= Soil resistivity (Ω-cm)
L_A = Anode length (cm)
X = Horizontal distance from anode to given point on structure (cm)

There are few factors which strongly contributing in current distribution, therefore it is important that it should be care while designing the system, i.e.;

1) The driving current from each individual anode should be less than the rated capacity of anode so that the desirable life can be achieved.
2) The current distribution in anodes should be uniform as possible either by controlling it through variable resistors in circuits or by varying cable sizes and lengths.
3) It is recommended that each individual anode resistance should be measured just after immediate installation. This data can be used in electrical circuit simulation software, which can give the idea about current distribution before system energization.
4) In case of multiple structures, an effective bonding system is required to make all structures electrically continuous.

Generally ICCP system with distributed anode bed system is commercially expensive in comparison with other CP protection methods but it is most effective way for plant piping.

5.4 Impressed Current Cathodic Protection System With Linear Anodes

The impressed current cathodic protection system with linear anodes is working on same principal as of distributed groundbed system. The difference is that, instead of using multiple anodes in uniformly distributed fashion, a linear continuous anode flex laid along the structure. Hence when activated, it gives ideally uniform current distribution along the entire length of structure. Following are some examples of such scenarios;

1) The electrical isolation of structures is not possible due to safety issues.
2) Uniform current distribution is not possible from remote groundbed due to structure complications.
3) Shielding of CP current due to underground incidental structures, like concrete foundation, pits, channels etc.
4) Structures in extremely congested areas like multiple pipeline corridors or in between carrier pipes and casings.

In designing of ICCP with linear anodes, the main and basic requirement is to calculate the anode-to-structure distance which gives sufficient polarization over structure that can be maintained within the protection criteria. Refer Figure – 3 which shows the arrangement of linear anode distribution over structure.

There are few factors which strongly contributing in current distribution, therefore it is important that it should be care while designing the system, i.e.;

1) The driving current in anode flex should be less than the rated capacity of anode so that the desirable life can be achieved.
2) There is current attenuation in anode, which gradually decreases the anode current output, therefore it is important calculate anode attenuation for finalizing the required length of anode and finalizing the location of anode-to-cable connection.

6. CONCLUSION

A plant design with a focus on proper survey like understanding the structures for new plant, current requirement for existing plant and soil resistivity for design basis for cathodic protection system is very important. Following are the best economical design for plant :

- ✓ The Sacrificial system for small section of isolated section of metallic structure.
- ✓ The Impressed current CP system with remote anode bed for soil resistivity less than 1,000 ohm-cm.
- ✓ The Impressed current CP system with distributed anode bed for soil resistivity more than 1,000 ohm-cm.
- ✓ The impressed current CP system with linear anodes is the best for buried plant pipelines in very congested area, where shielding is problem.

7. ACKNOWLEDGMENTS

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8. REFERENCES

1. Peabody's Control of Pipeline Corrosion (Second Edition), Edited by – Ronald L. Bianchetti
2. NACE - CP-2 Cathodic Protection Technician Course Manual.

Figure -1 Current Requirement Test Setup

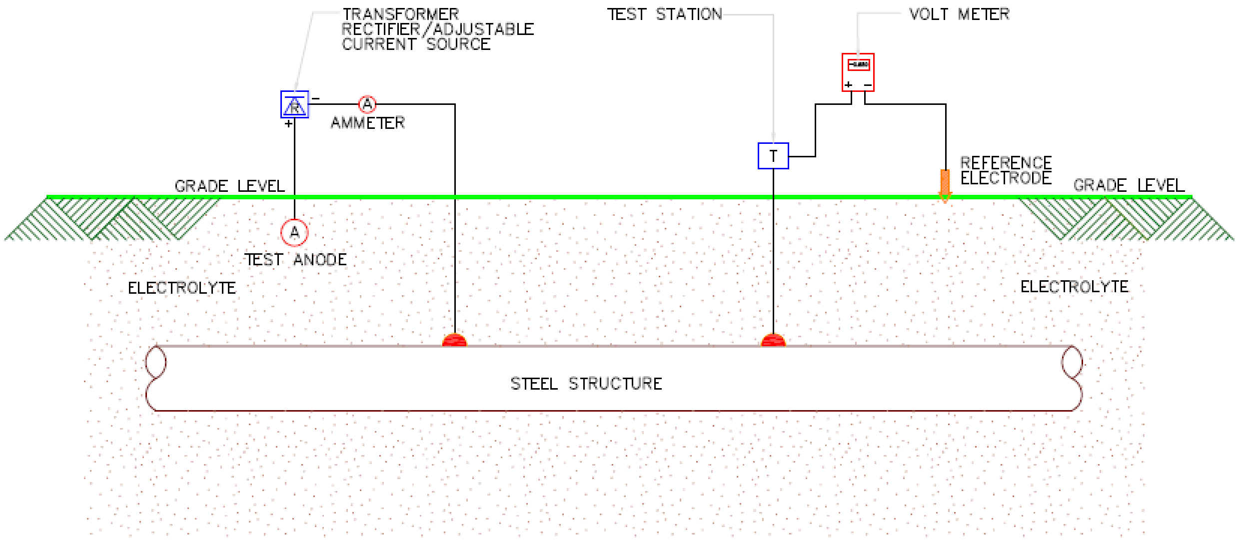

Figure - 2 Distributed Anode Bed Arrangement

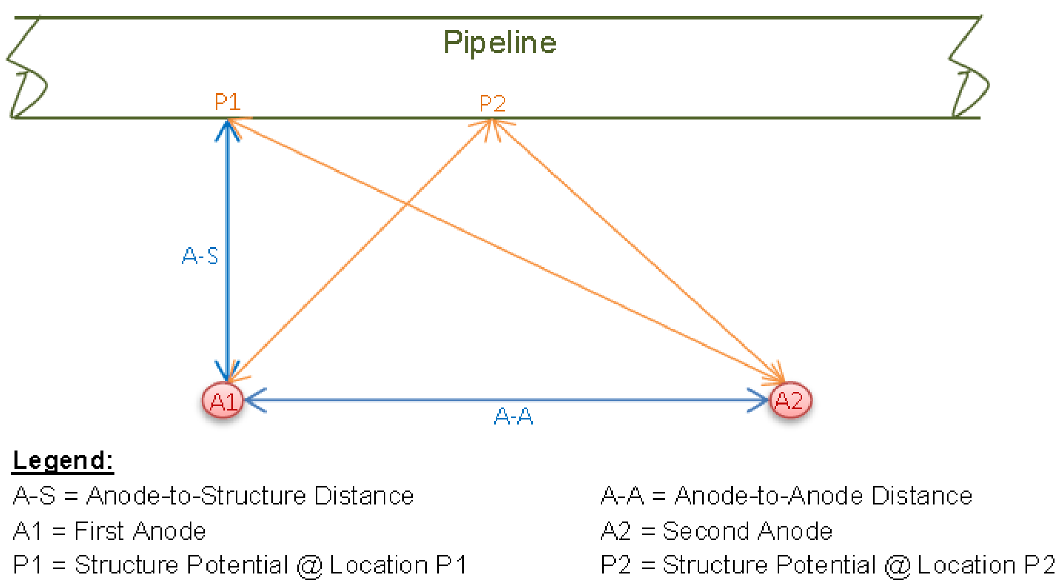

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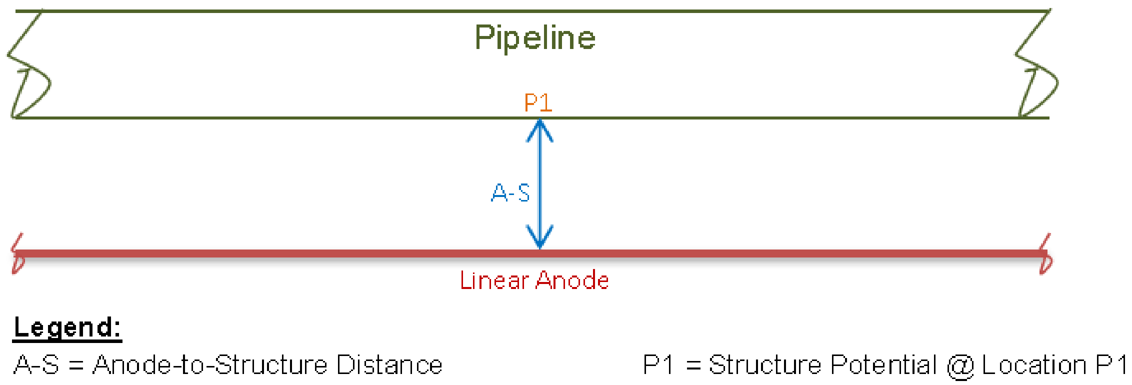
Figure - 3 Linear Anode Arrangement



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