PTT Exploration and Production Public Company Limited

PTTEP Engineering General Specification

(Engineering and Development Group)

Standard

Design of Cathodic Protection of Onshore Facilities

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1.0 INTRODUCTION

PEGS (PTTEP Engineering General Specification) is the PTT Exploration and Production PCL internal publishes standard. The objective of PEGS is to promote the best practices collecting from all PTTEP execution projects and to standardize those best practice to the future projects.

Every 5 years or upon request by the internal user, PEGS will be reviewed by related subject experts to reach decisions/agreements, then the document will be updated and publish to PTTEP intranet website. This is to ensure that all lesson learns from users can be applied to the future projects as the benefit to PTTEP.

2.0 PURPOSE

Purpose of the document is to provide a good practice in term of protection of oil and gas production facilities considered as complex structures against corrosion. It is to be used as general guidelines by corrosion and inspection engineers and corrosion engineers either for future or existing installations.

3.0 SCOPE

This document defines the minimum requirements for design, installation; monitoring and commissioning of external cathodic protection of buried piping, buried vessels, external side of tank bottoms, concrete reinforcing rebar, steel foundations etc. in onshore facilities such as pumping stations, compression stations, gas or oil treatment plants, tank farms, and well casings. Impressed current cathodic protection system shall be adopted when large buried surfaces are to be protected and when an electrical power source is available.

Unless otherwise specified, the cathodic protection system will be designed for a service life of 20 years minimum. The protection system's design should enable maintaining the polarization potential within the specified limits for 95% of the time.

The requirements of the present document supersede those of the reference documents.

Cathodic protection of pipelines is specified in 10008-STD-6-COR-022, PEGS-12059-COR-022.

4.0 RESPONSIBLE ACTION PARTIES

N/A

5.0 DEFINITIONS

A number of different terms are commonly used to describe the work stages, processes, and approvals which take place during the early stages of a development. This can often be a source of confusion so the following section is intended to show the PTTEP preferred terminology as used in this document.

5.1 LANGUAGE

In this document, the words should and shall have the following meanings:

Shall	Indicates a course of action with a mandatory status. The term “shall” shall be used if a requirement is considered to be necessary to claim compliance with a PEGS document.
Should	Indicates a preferred course of action. Should is a non-mandatory word and is not forbidden, but use in the body of the text should be the exception. Where none mandatory terms are used, each paragraph within these clauses shall also have an associated commentary paragraph that provides the rationale for why the stated choices and modifications are appropriate and circumstance under which the stated choices and modifications might be different.

5.2 TERMINOLOGY

Terminology	Description
Approval	The authorization in writing given by the COMPANY to the Contractor to proceed the work without releasing in any way the Contractor from any of his obligations to conform with the technical specifications, requisitions, etc. The words “Approve”, “Approved” and “Approval” shall be construed accordingly
Company	PTT Exploration and Production Public Company Limited and affiliates.
Contract Documents	The material requisitions, material specifications, etc. issued by the COMPANY and attached to the Contract or the Purchase Order
Contractor	Per contract: Contractor – ‘The contractor who is a PARTY to this CONTRACT and where the context so requires including, SUBCONTRACTORS utilized by CONTRACTOR for the performance of the WORK’
Manufacturer	The company or its sub-contractors selected by the COMPANY or the Contractor or the Supplier (as applicable) as the Manufacturer of the said material.
Purchaser	The COMPANY or the Contractor or the Supplier (as applicable) which have placed the Purchase Order to the Supplier/Vendor/Manufacturer.
Supplier/Vendor	The company designed on the Purchase Order form or Contract as being the selected supplier of the said materials.

5.3 COMMON ACRONYMS

Set out below in alphabetical order are common acronyms as found within this document:

3LPE	Three layer polyethylene
3LPP	Three layer polypropylene
CP	Cathodic protection
DC	Direct current
ERP	Electrical resistance probe
FBE	Fusion bonded epoxy
IC	Impressed current
T/R	Transformer rectifier

6.0 REFERENCES

The reference documents listed below, including Industry Codes and Standards and COMPANY specifications, form an integral part of this Engineering General Specification. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published on the effective date of a contract.

The overall order of precedence of the applicable documents shall be:

1. Applicable Laws, Rules and Regulations of the country in which the system/equipment will be operated (if any);
2. Purchase Order/ Service Order/ Contract Documents (Only applicable for direct purchase by COMPANY);
3. Project Particular Specification (PPS), and relevant data sheet(s) if any;
4. COMPANY General Specification;
5. Codes and Standards in reference.

Any conflict between any of the Contract Documents, or between this specification and any other Contract Documents, shall be reported to COMPANY for decision. In such a case, and unless otherwise agreed or decided by COMPANY, it is understood that the more stringent requirement shall apply.

Exceptions to, or deviations from this specification are not permitted unless previously accepted in writing by COMPANY. For this purpose, requests for substitutions or changes of any kind shall be completed with all pertinent information required for COMPANY assessment. COMPANY's approval, nevertheless, will not, in any way, relieve the responsibility of the Contractor to meet the requirements of the industry Codes and Standards referred to and amended herein, in the event of conflict.

6.1 PTTEP INTERNAL REFERENCES

Internal documents applicable to this document are indicated in the table below.

Document Number	Document Title
10008-STD-6-COR-010 , PEGS-12059-COR-010	Painting of Offshore Structures and Topside Facilities
10008-STD-6-COR-020 , PEGS-12059-COR-020	Design of Cathodic Protection of Offshore Structures
10008-STD-6-COR-021 , PEGS-12059-COR-021	Corrosion Spec on Design, Installation and Inspection of Cathodic Protection of Sealines by Sacrificial Anodes
10008-STD-6-COR-025, PEGS-12059-COR-025	Supply of anodes, monitoring equipment and other products for cathodic protection

6.2 INTERNATIONAL STANDARDS

International standards applicable to this document are indicated in the table below i.e. ISO, IEC or ITU.

Document Number	Document Title
API RP 651	Cathodic protection of aboveground petroleum storage tanks
EN 12954	Cathodic protection of buried or immersed metallic structures -General principles
EN 13636	Cathodic protection of buried metallic tanks and related piping
EN 14505	Cathodic protection of complex structures
NACE RP 0177	Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems
NACE RP 0193	External cathodic protection of on-grade metallic storage tank bottoms
NACE RP 0285	Corrosion control of underground storage tank systems by cathodic protection
NACE SP 0169	Control of external corrosion on underground or submerged metallic piping systems
NACE SP 0186	Application of cathodic protection for external surfaces of steel well casings
NACE SP 0286	The electrical isolation of cathodically protected pipelines
NACE SP 0572	Design, installation, operation and maintenance of impressed current deep ground beds
NACE TM 0101	Measurement techniques related to criteria for cathodic protection on underground or submerged metallic tank systems
NACE TM 0497	Measurement techniques related to criteria for cathodic protection on underground or submerged metallic piping systems

6.3 CODE AND OTHER STANDARDS

Codes, standards and regional legislation applicable to this document are indicated in the table below.

Document Number	Document Title
-	-

7.0 REQUIREMENTS FOR DESIGN OF CATHODIC PROTECTION OF ONSHORE FACILITIES

7.1 GENERAL REQUIREMENTS

7.1.1 DETAILS OF TASKS FOR THE DESIGN

Unless the contract specifies otherwise, a cathodic protection project shall include all of the tasks listed below.

- During a site survey, all relevant information/documents concerning the corrosivity of the environment (soil resistivity survey at site, presence of active bacteria), the presence of nearby metallic structures such as pipelines, existing plants, rails etc. (whether cathodically protected or not) and their metal-to-soil potentials, access points to the existing metallic structures, the presence of work likely to emit stray currents, the presence of high voltage cables or transmission lines, electric power stations, transformer stations and any system which, if faulty, may damage cathodic protection installations, coatings, or the structures shall be collected. Availability of electrical power for the supply of cathodic protection current, identification of non-hazardous areas for the installation of electrical equipment, and possible locations for anode groundbeds shall be checked. On the existing structures it would be possible to make some measurement (with the permission of the owner) to evaluate eventual current requirement. For the design of well casings protection, in situ determination of the required protection current should be done when necessary.
- All documents and information concerning the characteristics of the facilities to be protected (diameter, length, material of construction, quality of the coating material, and anything which is likely to influence the design of the cathodic protection system) shall be collected.
- A detailed study shall be carried out and a report covering the following aspects shall be issued to Company for approval:
    - Estimation of the corrosion risk based on the collected data and site measurements
    - Economical and technical evaluation of various anticorrosion systems for the protection of the facilities.
    - Justification of the selected design with design hypotheses, particularly for the insulation values of the coatings, and for ageing.
    - Description of the methodology used for the design.
    - Design notes justifying the sizing and layout of equipment: anodes, transformers-rectifiers, cables, etc.
    - A list of materials, including assembly accessories, and the corresponding technical specifications and datasheets, schematic diagrams and detailed equipment diagrams

- A list of possible suppliers.
- Detailed installation drawings indicating the location of insulating joints, electrical bonding to be installed, the layout of different types of equipment and the relevant installation procedure, and wiring diagram for electrical equipment
- Proper instructions and procedure for installation, indicating all precautions to be taken. Particular emphasis shall be placed on the construction of ground beds, connections on anode circuits, insulation between protected and non-protected parts, insulation between parts protected by different systems, remedial solutions to interference between the facilities to be protected and neighbouring work, and reference electrode installations at fixed points.

7.1.2 REQUIRED CERTIFICATION LEVEL FOR PERSONNEL

Design of CP systems shall be carried out by competent certified personnel. The level of certification of the individuals involved in the design shall be as follows:

- Conventional design work to be carried out by certified personnel at NACE level 3 or equivalent level 2 for certification AFAQ, AFNOR, APCE
- Complex design work to be carried out by certified personnel at NACE level 4 or equivalent level 3 for certification AFAQ, AFNOR, APCE

The qualification of each of the specialists working for such a design shall be demonstrated by the **Contractor** to the **Company** before commencement of the job.

7.1.3 QUALITY ASSURANCE PROCEDURES

At the beginning of the design, a Quality Plan must be drawn up by the **Contractor**, detailing all the actions related to the cathodic protection calculation, the definition of the systems to install, the material supply, checking and reception of equipment, and the commissioning on site. These shall be described in detailed procedures. All the calculations, systems, and materials that will be used shall be approved by the **Company**.

7.1.4 SUB-CONTRACTORS

The choice of sub-contractor(s) for any part of cathodic protection design and installation is subject to **Company** approval. Notwithstanding the above provision, the **Contractor** remains responsible for the successful completion of the cathodic protection project.

7.1.5 LEGAL AND ADMINISTRATIVE ISSUES

The following defines the **Contractor**'s and **Company**'s responsibilities when dealing with legal and administrative issues:

- If local legislation requires preparation of a legal file before installation of a cathodic protection system, the preparation of the file is the **Contractor**'s responsibility. However, **Company** is responsible to transmit the file to the competent administrative body. The **Company** shall also receive the results of the enquiry.
- **Contractor** is responsible for providing the **Company** with all the information and documents required dealing with the property matters, including extracts of land survey maps and delimitation on the land survey maps of the land to be acquired. However, the **Company** is responsible for answering any questions related to these matters. The **Company** shall likewise deal with the acquisition of land, settle all additional costs and compensate for any loss of crops.
- Contractor is responsible for carrying out formalities with the local energy distribution company if the installations require a power supply from the local distribution network. However, the network extension and connection costs shall be borne by the **Company.**
- Unless it is already available from the previous projects, all existing metallic structures (such as pipelines or railways, buried or in contact with soil) shall be identified and their owners shall be contacted by **Contractor**:
    - to obtain the necessary information concerning their structures (details of cathodic protection system, survey results, insulating joints, test points etc),
    - to obtain authorisation to carry out potential measurements and
    - to ascertain their particular technical requirements with respect to the new cathodic protection system.

7.2 SPECIFIC REQUIREMENTS

7.2.1 PROTECTION CRITERIA

After polarization, the “instant–off” metal-to-soil potential (“true” values after ohmic drop correction) of the carbon steel buried piping and equipment shall be:

- More negative than **-**850 mV/Cu/CuSO4 in aerated soil
- More negative than – 950 mV/Cu/$CuSO_4$ in an environment with possible development of sulphate reducing bacteria (de-aerated soil with confirmation of active bacteria presence).
- Partial polarization could be exceptionally accepted at some spots provided a shift of potential of -150 mV minimum.
- For the offshore parts (if any), the measured potential of the structure must be more negative than -800 mV relative to Ag/AgCl reference electrode.

The CP may have detrimental effects on some susceptible materials and cause Hydrogen Embrittlement due to the discharge of hydrogen atoms at the metal surface. Over-protection can cause coating disbonding. The instant –off potential of pipeline shall not be more negative than –1200 mV / Cu $CuSO_4$ electrode. For high strength steels (> 700 N.mm2), the instant-off pipe-to-soil potential shall not exceed –1100 mV / Cu $CuSO_4$ electrode in aerated soils.

For well casings, the above mentioned protection criteria will be verified near the well head.

Note: More specific protection criteria may be determined on a case per case basis subject to **Company** approval, according to facilities and materials characteristics, coatings and surrounding site.

7.2.2 COATING OF BURIED ITEMS

In order to reduce the corrosion risk and the current demand and to improve the current distribution within the facilities, an anticorrosion coating is applied on the buried piping and equipment.

The present specification is applicable to the items coated with epoxy, glass flake epoxy or glass flake vinyl –ester, polyurethane, three layers polypropylene (3LPP), three layer polyethylene (3LPE) and fusion bonded epoxy (FBE).

7.2.3 SOIL RESISTIVITY MEASUREMENT

The Wenner method shall be used for the soil resistivity measurements at representative areas. The depth shall be specified.

If there are significant soil resistivity changes during the year, the survey shall be carried out during the dry season.

If soil resistivity survey results are supplied to the **Contractor**, the **Contractor** may proceed to check them at random and at selected points for location of anodes.

7.2.3.1 AT LOCATIONS FOR IMPRESSED CURRENT (IC) ANODE GROUND BEDS

The soil resistivity shall be measured at the pre-selected areas for anode groundbed installation. These points shall be located in the vicinity of an available low voltage power source, in areas of low soil resistivity and outside any hazardous areas. For the selection of these locations, the existing, new or future structures, protected or not, shall be taken into account to prevent over potential and DC influences.

The soil resistivity shall be measured:

- at 80, 120 and 160 meters from the closest metallic structure for the shallow anode groundbeds,.
- at 20, 30 and 40 meters from the closest metallic structure for the deep anode groundbeds,

In complex process plants, shallow anodes are generally distributed within the facilities. Soil resistivity shall be measured at relevant locations.

7.2.3.2 RESULTS

The results shall be set out in the form of a table, specifying the places, corresponding resistivity values and useful observations for the design.

7.2.4 CATHODIC PROTECTION USING SACRIFICIAL ANODES SYSTEM

Cathodic protection by sacrificial anodes may be adopted:

- When the total buried surface area to be protected is small
- For local protection such as for vessels in concrete pits or remote isolated piping
- Exceptionally on larger installations when a power source is unavailable.

It should be limited to anode groundbed resistivity of less than 30 Ω.m.

7.2.5 COMBINATION OF IC AND SACRIFICIAL ANODE CP SYSTEM

If high resistivity soil is locally present at some location of the facilities, remote cathodic protection by IC may not provide necessary protection. Sacrificial magnesium anodes can be locally used, together with IC, to achieve the required protection level.

7.2.6 BURIED STRUCTURES THAT MAY BE SUBJECT TO STRAY CURRENTS

Structures that may be subject to stray currents shall be protected by IC systems with an automatic potential control. If an automatic potential control is required for part of the facilities then this condition shall apply to all buried structures to be protected.

7.2.7 ELECTRICAL INSULATION OF THE PIPELINE AND SAFETY DEVICES

For adequate protection, the facilities included in the scope of the project shall be electrically isolated, wherever necessary, from other metallic structures by installation of insulating joints or flanges.

If electrical continuity with other structures is required to prevent an over voltage /surge situation, adapted solution (polarization cell, surge arrester, isolating spark gaps or other) shall be submitted and approved by the **Company** to ensure the cathodic protection efficiency.

The type of insulation system proposed by **Contractor** shall be in accordance with safety rules with respect to over-voltage protection, and satisfy the requirements.

7.2.7.1 INSULATING JOINTS

The use of insulating joint shall be limited as far as possible. Insulating joints shall satisfy the requirements of the specification 10008-STD-6-COR-033, PEGS-12059-COR-033.

Insulating joints shall be installed at the limits of the facilities to be protected (change of owner) and used to insulate the facilities from the connecting pipelines. Installation of insulating joints inside the facilities shall be avoided.

The type of insulating joint shall be submitted to the **Company** for approval and shall satisfy the requirements of NACE RP 0286. The insulating joints shall comply with the construction requirements and operating conditions: steel grade, transported effluent, pressure, temperature, etc.

During installation particular attention shall be paid to avoid any short circuit that might be caused by a support, walkway fittings (valves), personnel protection systems or any other metal structure, whether temporarily or permanently installed. Insulation joints shall be installed aboveground or in a dry vault and on a straight pipe section.

If the transported effluent contains free water, the monolithic insulation joints shall be internally coated with glass flake filled vinylester coating (1 mm thick) for temperatures up to 120 deg C. In the case of insulating flanges, the pipeline shall be internally coated at both sides of the flange along the length (L) which depends on the aqueous electrolyte resistivity and on the pipeline diameter:

L = 400 x D / ρ

Where L is the internal coated length in centimetres. D is the nominal diameter of pipeline in centimetres and ρ is the electrolyte resistivity in Ohm.cm.

7.2.7.2 SAFETY DEVICES

Wherever needed (frequent lightning i.e. keraunic number normally over 21), the **Contractor** shall install safety devices such as surge diverters or polarization cells. The safety devices shall be in accordance with recommendation of NACE RP 0177.

7.2.7.3 EARTHING CIRCUITS

Earthing devices are required for security reasons. These devices are generally special equipment or composed of zinc alloy or galvanized steel buried in backfill. Compatibility of cathodic protection with earthing systems shall be studied and documented. In order to limit the current losses, the cathodic protection system shall be electrically isolated from earth circuits wherever needed.

7.2.7.4 SPECIFIC CASE OF ABOVEGROUND STORAGE TANK BOTTOM

The above ground storage tank bottom might require cathodic protection of external bottom plate surface. In that case cathodic protection system shall be designed and installed according to the recommendation NACE-RP-0193 and API 651.

For new construction Installation of cathodic protection shall be complemented by the following requirements:

- The tank cushion shall be constituted by clean washed sand, and in no case by a sandbituminous layer
- Bottom plates shall be coated.
- Impervious secondary containment membrane shall be installed approximately 50 cm below the tank.
- Anodic system will be constituted either by ribbon grid system, or by piggy back system, or by other pre-backfilled cable-like anode loop system, installed 30 cm below the tank plates.
- Distance between ribbon or cable anode will be 1.6 m maximum.

For existing tank, installation of dedicated cathodic protection shall fulfill the following rules:

- Sacrificial anodes or shallow grounded shall not be accepted.
- The electrical isolation of the tank versus foreign structure and earthing system shall be ensured.
- The cathodic protection shall be ensured by one or several deep groundbed anode.

Design shall be based on the tank surface and shall be submitted to Company for approval.

If those specific requirements for existing tanks cannot be achieved then tank bottom shall be considered as included with the other structures as a whole for the cathodic protection system design, but it shall be clearly stipulated that not guarantee of efficient cathodic protection can be achieved for those tanks.

Inspection program shall be implemented according to API 653 being assumed s that cathodic protection is not efficient

7.3 CATHODIC PROTECTION DESIGN METHODOLOGY

The design basis specified below may be adapted in the job specification for specific sites or conditions, or by the **Contractor,** subject to Company approval.

Cathodic protection design shall be based on the following principals:

- The amount of current provided by anodes at any time during the design life shall be sufficient to polarize buried piping and equipment according to criteria given in section 7.2.1 above.
- The weight of anodes shall be sufficient to provide necessary current up to the end of the design life.
- Unless justified by particular circumstances, any existing structure that may reduce the efficiency of the cathodic protection must be electrically insulated from the structures to be protected.
- Over protection shall be avoided
- The CP system shall not cause any interference to neighboring structures and pipes as far as possible. If interferences are unavoidable, equipement for correction shall be anticipated.
- If any extension of the facilities is known in advance, it shall be taken into account for sizing the cathodic protection equipment.

Note: If the onshore facilities include wells and flow lines, Company shall indicate, case by case, if a common or different Cathodic Protection system has to be provided.

Contractor shall prepare the calculation note for the IC system following the steps given below:

- Calculation of the total bare surface Sc and the surface to be protected Sp taking into account the coating breakdown factor (which depends on the ageing of the coating in time)
- Definition of current densities Id for bare metal surface considering type of material
- Calculation of total current demand for each coating breakdown factor and type of material to be protected.

- Calculation of total weight of anode material W based on the consumption rate (C) of the anodes to be used, the utilization factor (u) of the anodes and the design life.
- Calculation of number of anodes based on total anode weight W and individual anode weight Nw
- Calculation of the anode number based on the current output capacity of the anode Nc
- Calculation of final anode number as Nf = Max (Nw, Nc).
- Justification of the type of ground beds and ground beds locations
- Justification of the drainage points number and locations
- Calculation of anode, groundbed and cable resistances
- Sizing of DC sources

7.3.1 SURFACE TO BE PROTECTED

The **Contractor** shall calculate surface areas of:

- pipe works, tank bottoms, vessels and rebar that are to be intentionally protected by cathodic protection and
- bare earthing systems or similar systems that consume current as they are electrically connected to the network.

A contingency of 10% shall be applied to take into account small additional areas.

Buried items are externally coated at least with an anticorrosion coating. The cathodic protection is implemented to protect the bare metal surfaces at coating defects. For the calculation of the surface area to be protected the coating breakdown factor (fc) is to be used.

Surface area to be protected (Sp) is to be calculated as follows:

Sp = Sc x fc

Where Sc is the total coated surface area (including defects).

The following coating breakdown factors shall be used for 20 years of service life:

- 3LPP, 3LPE: 2%
- FBE: 5%
- Liquid applied coatings
- (e.g. Epoxy and glass flake filled resins): 15%

7.3.2 CURRENT DENSITIES

Below are the current densities (ID) applicable to the bare metal.

- Bare steel in soil: 20 mA/m²
- Bare galvanized steel: 40 mA/m2
- Bare copper in soil: 150 mA/m²
- Concrete reinforcements: 1 mA/m² (for the surface of concrete in contact with soil)
- Steel covered of cement: 10 mA/m².

Above mentioned values shall be increased by1 mA/m2 per °C above 25 °C.

7.3.3 TOTAL CURRENT DEMAND

In the design, bare and coated surfaces shall be considered separately.

The amount of total current demand I (mA) shall be calculated as follows:

$$I = Sp \times Id_1 + Sb \times Id_2$$

Where;

- Sp is the coated surface area to be protected
- Sb is the bare surface area (copper, rebar, and other bare surfaces)
- Id_1 is the required current density for the coated carbon steel
- Id_2 is the required current density for the bare surfaces other than carbon steel

Provision for possible current leakage shall be made, tank bottoms and well casings (if any) have to be taken into account depending on the the philosophy adopted for the insulation.

7.3.4 ANODE NUMBER

Anode number depends on the service life, the total current demand, the individual anode weight, the optimum current discharge from the anode and the anode consumption rate. The current output required at each injection point is produced by one or more anodes, the number of which (N) is defined as follows.

7.3.4.1 *ANODE NUMBER BASED ON ANODE WEIGHT REQUIREMENT*

The minimum total anode weight W (kg) to be installed in order to protect the facilities for the design life Y (years) is given by:

$$W = I \times Y \times C / u$$

Where:

- I: Total current requirement (A)
- C: Practical anode consumption rate (kg/ A.y)
- u: Utilization factor

The consumption rate (m) of anodic material is:

- 0.45 kg/A.year for Iron/Silicon/Chromium anodes
- 9 kg/A.year for scrap steel
- 0.010 kg/A.year for magnetite anodes
- Negligible for MMO (mixed metal oxide anodes on titanium substrate) anodes
- 7.3 kg/A.year for magnesium sacrificial anodes.

The utilization factor (u) of the anodes is as follows:

- For scrap steel, Iron/Silicon/Chromium and Magnetite anodes: 0.85
- For sacrificial anodes: 0.80.

The total number of anodes based on weight requirement (Nw) is obtained by dividing the total weight of anode W by the individual anode weight (M):

$$Nw = W / M$$

7.3.4.2 *ANODE NUMBER BASED ON CURRENT OUTPUT FROM ANODES*

Amount of current that can be produced by each anode depends on the anode size and anode material. For each material, there is a critical current density not to exceed. For example, for the silicon –iron chromium anodes the maximum current density is 20 A/m2. However, it is not suitable to use the anodes at the maximum limits. Typical practical current density for the silicon –iron chromium anodes is about 10 -12 A/m2. For the practical and maximum current densities, **Contractor** should refer to the anode **Manufacturer** data.

Typical maximum current densities for some anodes are as follows:

- Graphite: 10 A/m2
- Fe-Si –Cr: 20 A/m2
- MMO: 100 A/m2

The anode number based on the anode current output (Nc) is to be calculated as follows:

Nc = I / Cd x As

Where

- I: Total required current (A)
- Cd: Maximum current density for the anode
- As: Anode surface area

7.3.5 SIZING OF THE DIRECT CURRENT (DC) SYSTEM

7.3.5.1 *NUMBER OF DC SOURCE*

The number of DC sources distributed within the area is directly dependent on the current demand, global resistance of the CP systems, safety requirements and the limiting potential criteria as defined in Section 7.2.1. For complex cases, modelling of the system shall be carried out demonstrating that a right level of potential will be reached at each location during the whole design lifetime using software approved by the **Company**.

7.3.5.2 *OUTPUT VOLTAGE AND CURRENT CAPACITY OF THE DC SOURCE*

The design output voltage Ud (in V) and the design current output Id (in A) of the DC source (normally a transformer/rectifier set) shall be as follows:

- Id ≥ 1.25 x I
- Ud ≥ 1.2 x R x I

Where

- I: Total required current (A)
- R: Maximum overall resistance (Ω) calculated according to section 7.5.3

- 1.25 (for Id) and 1.20 (for Ud) are safety factors

Unless otherwise exempted, the DC voltage (U) shall not exceed 50 V.

7.3.5.3 *CALCULATING OF OVERALL RESISTANCE*

The overall resistance (R) of the system is equal to:

$$R = Ran + Rca + Rl$$

Where:

- Ran: Resistance of the anode groundbed (Ω)
- Rca: Total resistance (Ω) of the cables connecting anodes and the pipelines to the DC source
- Rl : leakage resistance of the structure

7.3.5.4 *ANODE RESISTANCE*

Unless otherwise stipulated, several "anode ground bed" configurations may be considered, depending on the dimensions of the installation, the apparent resistivity of the ground at the selected point and the environment. Calculation resistance method is given in ANNEX 1.

7.3.5.5 *CABLE RESISTANCE*

The resistance of the cables (positive and negative circuits) is calculated from the following formula:

$$Rca = \rho o \times (lc / sc)$$

Where:

- ρo: Resistivity of the cable core at 20°C (Ω.m), equal to 0.18 μ ohms.m for copper
- lc: Length of cables considered (m)
- sc: Cross-sectional area of the cable core (m^2).

Generally the resistance of the cable per unit length for a specific diameter is provided.

7.3.5.6 *LEAKAGE RESISTANCE*

Unless justified by a specific calculation which shall be approved by the **Company**, the leakage resistance of the coated structure relative to remote earth is calculated at first approach from the following formula:

$$Rl = Rf / Sb$$

Where:

- R**f**: Faradic resistance of steel, equal to 5 ohm.m^2 at 10 ohm.m electrolyte resistivity (proportional for higher resistivity),
- S**b**: Surface of bare steel

In case of significant copper grounding connected to the structure, resistance of coated structure will be considered as negligible.

7.4 CP MONITORING DESIGN

CP potential monitoring is usually carried by using portable reference electrode and voltmeter (or data collector). To this, end test station shall be provided. Contractor at the design stage shall define the numbers and locations.

Permanente reference electrodes can be specified at critical test stations, with or without test coupon as the following locations :-

- road and rail crossings of the pipes at both sides of the casing,
- insulating joints,
- interconnection point between structures (parallelisms and crossings),
- crossings with an unprotected metallic structure or foreign structure
- current drain points
- anodes and groundbeds

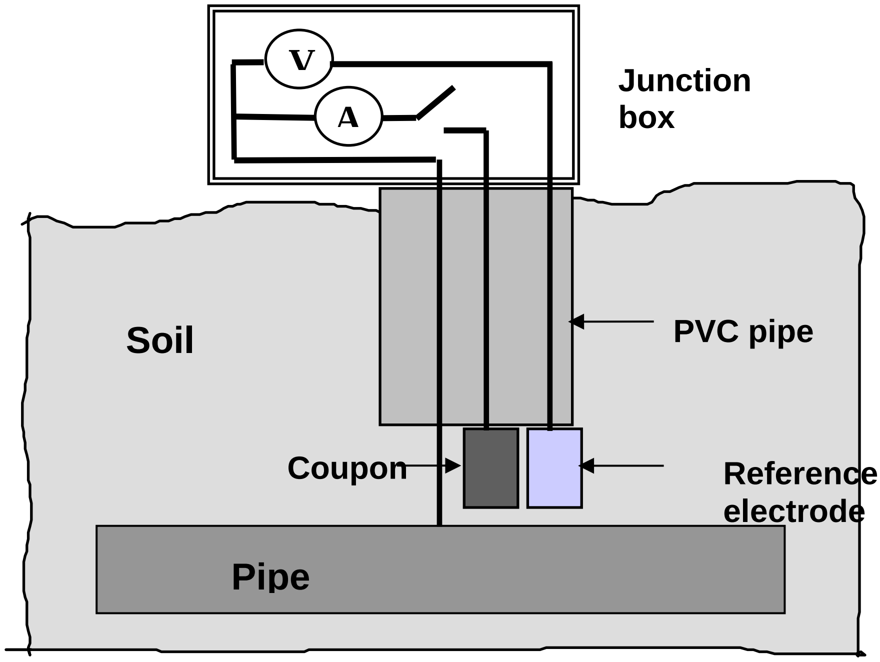


Figure 1 – CP monitoring

The number and location of permanent reference electrodes shall be determined by the **Contractor**. However, one electrode shall be provided at each:

- Areas where stray currents are expected
- Where piping /equipment is buried more than 3 m deep

- Where the surface is asphalted or concreted

Collection of influence

Where existing foreign structures could be influenced by the CP system, provision should be anticipated to allow influence correction such as junction boxes with resistor and diode.

7.5 EQUIPMENT SUPPLY

Unless otherwise specified, the supply of following items is responsibility of the **Contractor**:

- All necessary equipment according to design requirements
- The spare parts recommended by the **Vendor** for a two year operations
- The spare parts which might be required during the starting-up of cathodic protection.

The **Contractor** shall provide **Company,** in due time, with the provisional manufacturing schedule to allow Company to make necessary inspections and quality control during manufacturing process to be sure that the equipment complies with Company specifications and relevant standards.

The Contractor shall provide Company with the following information for each item /equipment

- Factory test reports
- Chemical analysis for anodes
- Certificates of approval for electrical equipment to be used in hazardous areas
- The Vendor's drawings and the operating and maintenance instructions
- The list of spare parts for two years of operation, with complete references

All of the materials shall be designed to withstand the specified climatic conditions.

7.5.1 TRANSFORMER / RECTIFIER

7.5.1.1 *GENERAL CHARACTERISTICS*

The transformer will normally be of the air cooled type (natural or forced convection). However, for an outdoor installation in desert climate conditions an oil cooled type is preferred.

The rectifier stack shall be of the silicon diode type, connected for full wave rectification. The silicon diode shall be rated to a minimum of 120% of the nominal current output rating of the unit.

Rectifier output control shall be thyristor controlled. Output should be continuously variable from 0 to 100% of rated output. The AC ripple voltage shall be controlled not to exceed 5% of DC output for the range 5 – 100% of full output rating. Both “constant current” (controlled by transducer) and “constant voltage” (DC output voltage control) operating output control modes shall be possible.

Constant potential (control of measured potential relative to an external permanent reference electrode) operating control should be specified on a case-by-case basis for specific purpose, subject to **Company** approval. In this case (constant potential mode), the unit shall be capable of reading the potentials of up to three external reference electrodes and taking an average of these for control. To eliminate spurious readings, all values out of the pre-determined range shall be rejected.

The transformer rectifier (T/R) shall be equipped with a breaker allowing ON/OFF potential measurements. The type and characteristics of breakers shall be adapted to the maximum nominal current output. When more than two CP stations are necessary, breakers shall be such that precise synchronisation of ON/OFF cycles is ensured.

The control of the transformer rectifier current output could be manual or automatic. For manual control, tap setting shall be avoided.

The control, regulation and protection devices shall be installed inside the cubicle and accessible.

For the rectifiers and regulation units, the power equipment (transformer, rectifier bridge, ballast transistors) shall be placed:

- Inside the cubicle, with the insulated components to avoid any contact or short circuit during maintenance or adjustments.
- If necessary, in a mineral oil-filled tank, fitted in the upper part with a filling hole, a thermometer and an oil sight gauge, and in the bottom part with a drain valve (outdoor transformer-rectifier for desert areas).

The equipment shall be suited to the chosen location (inside a building or outside, under shelter or not) which shall in all cases be situated outside of any hazardous area and accessible at all times. Minimum IP rating for indoor installation shall be IP31 for overall construction and shall consist of dry type transformer. For outdoor installation, minimum IP55 applies.

7.5.1.2 *TESTING*

Each transformer-rectifier shall be subject to factory quality inspection by company representatives. This inspection shall be defined in the job specification and shall include at least:

- A visual and mechanical inspection of conformity
- Heat run testing at no load, 50% load and full load with calculation of efficiency
- 1000 V megger insulation resistance test for the following:
  - Primary to Secondary
  - Primary to Earth
  - DC Positive to Earth
  - DC Negative to Earth
  - DC Positive to DC Negative

  The resistance value shall not be less than 10 M Ω before the heat run test.
- Breakdown test 2 kV for 1 minute.
- A check on the wiring diagram and the operating manual provided.

For self-powered DC sources, the **Contractor** shall submit a quality inspection plan to the Company, accompanied by inspection and test procedures, for approval.

7.5.2 IMPRESSED CURRENT ANODES

The basic option for the impressed current anodes is high silicon iron (Fe/Si) anodes with or without added chromium. Other types of anodes such as mixed metal oxide (MMO) anodes, graphite anodes, scrap steel, or magnetite anodes can be used, depending on the soil characteristics and subject to Company approval.

The alloy composition of Fe/Si anodes shall comply with the chemical composition given below.

Element	Grade with chromium % (Fe-Si-Cr)	Grade without chromium % (Fe-Si)
Si	14.25 - 15.25	13.50
Mn	0.50	0.75
C	0.70 - 0.80	0.95
Cr	4.0 - 5.0	-
S	0.60 max	0.75
P	0.10 max	0.25 max

The anodes shall be supplied/fitted with the specified electrical cable and ready for installation, delivered preconditioned or not in a backfill column (canister).

7.5.3 BACKFILL

The backfill comprises 99 grade petroleum coke breeze, containing at least 98% carbon, with a particle size ranging from 0.2 to 0.7 mm and a maximum resistivity of 25 Ω.cm. This type of backfill shall be used where there is no water table influence, because of a specific weight below 1 kg/dm3. Where there is influence from water tables, the backfill may be :-

- Installed in a geotextile packing containing coke breeze and anodes, if water table can be temporary removed using pumps, allowing enough time for installation.
- Otherwise composed of bentonite (25%), gypsum (70%) and sodium sulphate (5%) mixed with water to form a compact mud. In this case, the lack of beneficial effect of coke breeze on anodic reaction shall be taken into account for the determination of anode lifetime.

For the factory preconditioned anodes, the backfill and anode are placed in a closed cylindrical steel "canister" made of spiral wound galvanized steel sheet with a minimum thickness of 0.5 mm, or preferably installed in a backfill containing a geotextile bag. The anode shall be centred inside the backfill. The dimensions of the canister or the bag shall be adapted to the dimensions of the anode, within the following limits:

- External diameter at least three times that of the anode (and 12 cm at minimum)
- Length at least 1.3 times that of the anode.

The canister extremity with the cable connection shall be fitted with a cable gland and a lifting handle, to avoid damage to the cable during handling and installation. In the case of the geotextile bag, the ends of the bag shall be fitted with a closing device (for example, a plastic collar). On the cable entry side, the cable will do a tight loop inside the bag near the closing device, to avoid possible damage of anodic connection during handling.

The **Contractor** shall deliver the anodes together with the following documentation:

- Chemical analysis certificates of the castings
- Certificate of conformity of the cable-to-anode core connection. The connection resistance shall be below 0.06 Ω.
- A test certificate of the mechanical resistance of the connection, carried out on 5% of the anodes, and for which the minimum required value is 200 kg for Fe/Si anodes, with or without chromium
- A visual and dimensional inspection certificate.

7.5.4 CABLES

All cables shall comply with the regulatory requirements. They shall be clearly identified by suitable labels

Connections to the structures shall be:

- By thermit welding or electrical discharge pin brazing directly on the structure or on a welded steel plate, depending on the steel characteristics
- By bolting to a welded steel plate (50 x 60 x 6 mm), with a 13 mm hole drilled in its centre. The bolts and nuts used to fix the cable lug shall be of brass
- In any case, the choice to use or not a doubler plate, and the welding process for the connection has to be in full compliance with the relevant Company specifications and approved on a case by case basis.

Any buried connection shall be insulated from the surrounding electrolyte by a suitable mastic such as cold cure epoxy. Each cable shall be secured on top of pipe by means of plastic collars.

7.5.4.1 *ANODE CABLES*

The anodes may be connected either

- To the main anodic circuit or
- Individually and directly to a junction box.

Note: Anodes should be preferably connected to a junction box equipped as necessary with adjustable resistor in order to allow the balance of the current on each individual anode so that the consumption rate of each anode will the same.

In the first case, the length of anode cable shall be as short as possible, but not less than 2 m. In the second case, the cable section shall be determined to keep the voltage drop in the cables as low as possible.

Cable shall be connected to the protected structure using doubler plates. This connection shall be protected, preferably with epoxy resin, to prevent any possibility of water ingress into the connection.

7.5.4.2 *MAIN CIRCUIT CABLES*

For an impressed current system, these are cables between

- Anode cables and the positive pole of the T/R unit (preferably through a junction box) for the positive DC current. The cabling between anodes, or junction box, and T/R shall be ensured by cable loop.
- Structure and negative pole of the T/R unit (eventually through a junction box) for the negative DC current

For a sacrificial anode system, these cables shall include the bonding limks between the anode ground bed and a test / junction box and, on the other side, between the protected structure and the same box.

The cables shall be flexible or semi-rigid copper cables, with double insulation (PE/PVC, XLPE/PVC or PVC/PVC).

The cross-sectional area of the main cables shall be defined considering the maximum current supply from anodes and minimum voltage drop in the cable especially if the length of the cable is important. The minimum cross section for the main cables shall be 16 mm^2.

7.5.4.3 *GROUNDING CABLES*

They shall be in compliance with the regulations in place. Generally insulated copper cables, semi-rigid and rated according to the standard concerning low voltage electrical installations are used.

7.5.4.4 *MEASUREMENT CABLES*

These cables are used to carry out the various cathodic protection measurements, independently of the other link cables. Each conductor shall have a minimum cross-sectional area of 16mm^2 and should be prefered for mechanical resistance reason. The nominal voltage allowed for these cables is 450/750 V.

7.5.5 SACRIFICIAL ANODES

The sacrificial magnesium anodes may be used bare where soil resistivity is below 10 Ω.m. Other sacrificial anodes (zinc and Al-In) are not used for the protection of buried pipes against corrosion. Magnesium anodes shall be supplied preconditioned in a non-hydrated regulating compound ("backfill"). For anode characteristics refer to 10008-STD-6-COR-025, PEGS-12059-COR-025.

The backfill used with magnesium and zinc anodes shall comply with the following composition requirements:

- 75% gypsum ($CaSO_4 – 2H_2O$)
- 20% bentonite
- 5% sodium sulphate (Na_2SO_4)

The weight of the backfilled surrounding each anode shall be at least equal to the net weight of the anode and be contained in a geotextile bag.

7.5.6 JUNCTION BOXES

They provide a minimum of protection against shocks and the ingress of water. They are made either of insulating material (PVC, polycarbonate, etc.) or metal (steel, cast aluminium, stainless steel) considering specific climatic conditions.

They are generally installed in non-hazardous areas so that they can always be accessed when required. Generally the following is requested

- IP 55/IK 08 for outdoor locations
- IP 31 for indoor locations.

In hazardous areas they shall comply with safety regulations.

The cables shall be easy to disconnect for measurements and their entry into the junction box shall be via cable gland of metal or insulating material, or via support pipe according to the type of box selected.

7.5.7 MONITORING EQUIPMENT

7.5.7.1 *TEST STATIONS*

Test points shall comprise:

- A junction box, as defined in Section 7.5.6, with required internal accessories and a lockable opening. All terminals, shunt strips, resistors, diodes, surge diverters, etc shall be fitted on an insulating plate located in front of the opening.
- A 3" or 4" pipe made of rigid PVC or metal (75 to 100 mm in diameter) to support the junction box and protect the cables. In all cases, the length of the pipe shall be at least 1.5 m

Note: Steel frame support shall be accepted.

In some cases, a junction box may not be needed. The extremities of cables shall be fitted on an insulating plate in the supporting pipe with a lockable opening at the top of the pipe (tubular test station).

In urban areas, except within the fence and wall limits, these test points shall comprise a junction box placed inside a concrete pit or vault <u>for a case of pipeline</u>.

In hazardous areas the boxes shall meet the requirements of applicable safety standards. In all instances box model shall be submitted to the COMPANY for approval.

7.5.7.2 *PERMANENT REFERENCE ELECTRODES AND COUPONS*

These electrode are used to monitor the effectiveness of the cathodic protection system, the pipe-to-soil potential at a specific location. The measurement can be done directly or via a remote monitoring system.

The permanent reference electrode shall be either:

- $Cu/CuSO_4$, the electrolyte compound shall comprise of 1/3 bentonite and 2/3 copper sulphate, which replaces the gelatine of the portable electrode, shall be contained in a porous pot cylinder at least 100 mm in diameter and 200 mm high. The top part of the cylinder shall be closed with a cold cure hard mastic or equivalent. The length of the copper cable shall be sufficient to make direct connection to the junction box or surface monitoring system.
- Pure Zinc reference electrode embeded in a backfill. The composition of the zinc will be the following:
  - Aluminium: 0.005 max
  - Cadmium: 0.003 max
  - Iron: 0.0014 max
  - Lead: 0.003 max
  - Copper: 0.002 max
  - Zinc: remainder (99.995 min).

  The backfill composition will be:

  - 75% of anhydrous calcium sulphate
  - 18% of bentonite
  - 5% of anhydrous sodium sulphate
  - 2% of sodium chlorite.

The location and number of permanent reference electrodes shall be determined in the detailed study of the system by the CONTRACTOR.

Before energizing, the permanent zinc electrodes shall be immersed in fresh water for at least 24 hours to ensure that the bentonitic compound is completely humidified.

The permanent reference electrode shall be assumed to be stable 72 hours after its total immersion.

7.5.7.3 *COUPONS*

At an appropriate location, coupons shall be supplied and installed with local ON/OFF measurements together with cathodic current density measurements. This is especially required in complex areas. Coupon shall be circular and shall be assembled at the end of a PVC tube. This tube will allow a portable reference electrode to be inserted from surface.

Contractor shall propose all information about the coupons, location and equipment proposed for **Company** approval. A typical coupon drawing and installation is given in annex 2.

7.6 INSTALLATION

7.6.1 INPRESSED CURRENT DC SOURCES AND TRANSFORMER RECTIFIER

As a general rule, the location of electrical equipment in hazardous areas shall be avoided. If this is impossible, the use of equipment corresponding with the safety classification of the area in question shall be specified.

Indoor wall-mounted air-cooled transformer-rectifier sets shall be installed inside a technical building or shelter, and in a well ventilated place that is easily and permanently accessible. For outdoor installation, they shall be located outside the perimeter of the hazardous area in accordance with safety regulations. If this is not possible, all of the components for adjustment, monitoring, protection and connection, including the cubicle, shall satisfy the requirements relating to electrical apparatus located in potentially explosive areas. In that case, air cooled T/R are usually preferred.

Self-powered DC sources shall be located outside the hazardous area and within an enclosed area bounded by a fence, with the control and monitoring cubicles located inside a shelter.

The layout shall be executed in accordance with the **Contractor'**s instructions, drawn up in accordance with local regulatory requirements concerning low voltage electrical installations.

7.6.2 JUNCTION BOXES

The junction boxes shall be mounted on a metallic support (steel pipe) anchored in a concrete base. Where cable entry is by cable glands, cables shall be routed up from the concrete base via cable tray used for fixing and protection purposes.

If the junction boxes are made from metal, in order to minimize any safety issues to the personnel due to electrical shock, it is recommended to install suitable grounding system(s) for the junction boxes. CONTRATOR shall provide detail drawing and installation of the grounding system and subject to the COMPANY approval.

7.6.3 TEST POINTS

The test points shall be installed within the plant at selected locations as detailed in section 7.5.7.

In asphalt or concrete areas, regular access shall be provided to the natural soil for potential measurement near or above the protected item at the test point locations. These access points shall comprise a rigid PVC tube, 75 to 100 mm in diameter, extending to the surface and closed by a removable cap.

7.6.4 CABLES

The positive and negative circuit cables, including those of the permanent reference electrodes, shall be buried to a depth of 0.8 m on a sand bed with a warning mesh placed 20 cm above, or laid in specially provided underground concrete or plastic ducting.

All cables shall be suitably tagged inside the cathodic protection equipment (transformer rectifier, junction boxes, and test points) and left unconnected until commissioning.

7.6.4.1 *ANODE CABLE / MAIN CABLE CONNECTION*

To guarantee the continuity of the current supply to anodes in case a cable is cut during an accident, the cable of the impressed current anodes shall be built in a loop.

At the point of anode cable/main cable connection, the insulation of the main cable is to be removed over 4 to 5 cm to allow connection of the anode cable, itself stripped over 2 to 3 cm, by clip-screwed or crimped connector. The main cable must not under any circumstances be cut. After checking mechanical strength and electrical continuity, the connection shall be insulated by a cold cure epoxy resin into a mould previously placed around the joint and sealed at each end. The connection shall not be handled until the resin is completely cured as per the data sheet of this resin.

For a sacrificial anode system, cables shall include the bonding links between the anode ground bed and a test/junction box and, on the other side, between the protected structure and the same box.

7.6.4.2 *CABLE CONNECTIONS TO THE PROTECTED ITEM*

Direct welding of the cable to the item to be protected is not allowed. In all cases a doubler plate (50 x 60 x 6 mm with a 13 mm hole drilled at the centre) shall be seal welded to the item for cable connection. The welding procedure for the doubler plate welding is subject to **Company** approval. This connection, located on top of the line, shall be executed:

- By thermit welding or electrical discharge pin brazing on the doubler plate for the buried connections. In all cases where any pin brazing method or aluminothermy method is applied, a fully qualified procedure shall be required in accordance with the relevant piping / equipment specifications.
- By bolting to the doubler plate for the above ground connections. Galvanised bolts and nuts shall be used to fix the cable lug.

Any buried connection shall be insulated from the surrounding electrolyte by a suitable mastic such as cold cure epoxy. The surface shall be brushed clean prior to coating to a grade of cleanliness ST 2 as specified in ISO 8501-1.

The cable shall not be wound around the piping/equipment. Extra 0.5 m long cable shall be available around the cable connection.

7.6.4.3 *PERMANENT REFERENCE ELECTRODES AND COUPONS*

Before using, the permanent Cu-CuSO4 electrodes shall be immersed in fresh water for at least 24 hours to ensure that the bentonitic compound is completely humidified. The permanent reference electrode shall be assumed to be stable 72 hours after this 24 hours of immersion.

Coupons shall be installed as close as possible to the metal surface (no more than 10 cm from the surface) and also to the reference electrode. Coupon and permanent reference electrodes shall be positioned either above the centre line or on the sides at mid-axis of the piping or equipment in compacted stone-free natural soil.

After installation, the reference electrodes and coupons shall be sprinkled with 20 to 30 litres water.

Then the permanent electrode potential shall be checked against a calibrated portable reference electrode (Cu-CuSO4 or calomel) positioned nearby.

7.6.5 ANODES

7.6.5.1 *MAGNESIUM ANODES*

These pre-conditioned anodes shall be soaked in fresh water for 24 hours prior to installation.

The anodes shall normally be located at a short distance from the protected structure. They shall normally be laid horizontally in the bottom of the trench. The trench shall be perfectly backfilled after installation.

7.6.5.2 *IMPRESSED CURRENT ANODES*

The location of impressed current anodes shall depend on the following parameters:

- Availability of energy source
- Low soil resistivity
- Non- hazardous area
- An excavator can have access.
- Shallow anodes shall be at least 80 meters away from the nearest metallic structures and anodes. Anodes installed in a deep well shall be at least 25 meters from metallic structures and anodes. If these limits cannot be respected, necessary measures shall be undertaken to limit the anodic influence on such structures.

- A detailed study shall define the land occupation of the anodic ground bed, spacing between anodes, and the depth and routing of the cables. In case of high soil resistivity, the number of anodes / groundbeds shall be adjusted in such a way that the groundbed dimensions will not exceed the available land dimensions. Installation of a permanent watering system shall be investigated in case of very high soil resistivity.

After anode installation in the trench, the groundbed shall be watered, if necessary, before final backfilling. The backfilling shall be carried out after slight tamping of the backfill around the anodes, with all stones removed from the soil. Upon completion, each anodic ground bed location shall be marked at both ends and at ground level by a concrete or coloured plastic marker.

For vertical anodes in deep columns, the requirements of NACE SP 0572 shall apply.

7.7 COMMISSIONING

A detailed schedule for commissioning, drawn up by the **Contractor** and including preliminary and final operations shall be submitted to the **Company** for approval.

The commissioning of the cathodic protection system shall not take place until all the welding, insulation, wiring and civil engineering work has been completed on the protected structures.

Commissioning shall be supervised by a Contractor and attended by Company representative and Company personnel responsible for the maintenance of the system(s) in the future.

7.7.1 *NATURAL POTENTIAL MEASUREMENT AND START UP OF CP SYSTEM*

Following procedure shall be used.

a) Before connecting the pipeline to CP system (and to any sacrificial anode, if any):

- Verify the proper installation of the CP monitoring system (coupons, ER probes, permanent reference electrodes etc.) and to measure the corrosion rate (by ERP) without cathodic protection and the natural potential of the coupons
- Measure the natural potential of the structure to be protected and all connected structures (En), to be protected or not, at all test points.
- Check the possible presence of stay current.

b) To make all electrical connections (cables inside the junction boxes and to the DC sources) and to verify the proper functioning of each DC source:

- Check the power supply voltage and DC output voltage (Uo) off-load (0 to 100%)
- Power up and measure DC characteristics (current I, voltage U and potential E at the drain point) for 25%, 50% and 100% of nominal rating of the DC source.
- If some sacrificial anodes are part of CP system, connect them to the structure and set the variable resistor, if any, to zero, measure the current output, set the variable resistor

maximum value and measure the current again. Also measure the structure potential during the current measurement operation.

- Adjust each impressed current DC source to obtain the minimum protection level everywhere on the structure by measuring ON/OFF potentials at tests points (and wherever else needed using a portable reference electrode). Areas with over protection and under protection, if any, will be recorded.
- Adjust the uniform repartition of the current on each anode.

7.7.2 *MEASUREMENTS AFTER POLARISATION*

After energising the CP system, sometime will be needed to reach the required level of polarisation.

After the measurements at minimum setting (section 7.7.1, above) and a period of 48 hours, the **Contractor** shall take final readings and re-adjust the protection level if needed by measuring ON/OFF potentials at tests points (and wherever else needed using a portable reference electrode).

Final readings on the sacrificial anodes shall be taken as for the impressed current system.

For an automatically controlled system, the **Contractor** shall set up the regulation parameters to maintain the protection level within the specified minimum-maximum range.

If the protection level exceeds the lower limit, and there is a risk of detrimental overprotection either to the steel (embrittlement) or to the coating or painting system (disbonding), the anode current output shall be limited by installing a variable resistor, if not yet installed, or by disconnecting some of the anodes.

7.7.3 *INVESTIGATION AND ELIMINATION OF INTERFERENCE*

Contractor shall make necessary investigations and measurements and take necessary remedial actions to guarantee that:

- The CP applied on the structure (to be protected) is not interfering with the crossing or parallel structures/pipelines.
- The CP applied on the neighbouring structures and pipes are not interfering with the protection of the structure (to be protected).

For potential variations greater than 50 mV, a correction must be decided on between the involved parties.

7.7.4 *VALIDATION*

All results shall be submitted to the **Company** before demobilization to confirm their compliance with Company requirements. In case of non-conformity (especially missing measurements) or unexplainable results, the **Contractor** shall complete or correct the inspection results.

If the protection level is not adequate, **Contractor** shall carry out corrective actions as dictated by the inspection results. These actions may be linked to non-conformities regarding either the coating or the cathodic protection. In the absence of particular contractual clauses, the non-conformities shall be subject to repair. The repair procedure shall be submitted to the **Company** for approval.

A further series of measurements shall be performed in the first three to four months of operation after commissioning. The results shall then demonstrate the effectiveness of the cathodic protection system. The subsequent schedule of routine inspections shall be drawn up by the Contractor.

Contractor shall ensure the training of the Company personnel in charge of the CP system operation and maintenance.

7.8 TECHNICAL FILE

Upon completion of work, Contractor shall supply a technical file including:

- The characteristics of the structures protected
- Site survey results
- Hypotheses considered for the design
- Detailed CP design calculations.
- Chosen anode material, the data sheets and test certificates of the materials/equipment
- The detailed as built drawings/ wiring plans providing all details about installation
- The operating and maintenance instructions and operating procedures
- Natural and Cathodic protection potentials obtained during the commissioning.
- The equipment list with references and Vendors' addresses
- The list of spare parts for two years of operation, with complete references
- The reports stating the agreements taken with the owners of the neighbouring structures (duly signed by the various parties concerned) on the corrective measures to be taken for any interference of these structures.
- The results of the enquiry and the permission of the local authorities if the installations are to be in countries where such installations are subject to special legislation.

8.0 APPENDICES

Appendix 1. Ground Bed Resistance Calculation

<u>Calculation of the vertical anode resistance **without backfill**:</u>

- For a single vertical shallow anode, without backfill, the resistance is

  $$Ra = (\mathbf{r}\ / (2\ p * L)) * (Ln\ (8 * L / D) - 1)$$

  Where

  Ra : Anode resistance (ohm)

  r : Resistivity of the environment (ohm. m)

  L : Anode length (m)

  D : Anode diameter (m)

- For a single vertical deep anode, without backfill, the resistance is

  $$Ra = (\mathbf{r}\ / (2\ p * L)) * (Ln\ (4 * L / D) - 1)$$

  If several single anodes (vertical shallow or vertical deep) are in parallel , without backfill, it is necessary to calculate the interference factor “f “ as defined below:

  $$f = 1 + ((2L/S) * Ln\ (0.656*N)/(Ln(8L/D)-1)).$$

  $$Rt = Ra * f / N$$

  Where:

  Rt: total resistance of N anodes (ohm)

  N: number of anodes

  S: distance between two anodes

- If several single anodes are in parallel, without backfill, it is also possible to use Sunde Equation for ground bed resistance calculation. This equation already includes the interference factor:

  $$Rt = (r\ / (2\ p * N * L)) * (Ln\ (8 * L / D) - 1 + (2L/S) * Ln\ (0.656*N)).$$

<u>Calculation of the vertical anode resistance **with backfill**:</u>

- In the case of a single vertical anode with backfill, the resistance of the anode can be calculated as follows:

  <u>Step 1</u>: calculation of the single anode resistance to backfill

  $$Ra = (r\ / (2\ p * L)) * (Ln\ (8 * L / D) - 1)$$

  Where:

  Ra : Anode to backfill resistance (ohm)

r : Resistivity of the backfill (ohm. m)

L : Anode length (m)

D : Anode diameter (m)

Step 2: calculation of the backfill resistance to soil

Rg = (r / (2 p * L)) * (Ln (8 *L / D) - 1)

Where:

Rg : backfill to soil resistance (ohm)

r : resistivity of the soil (ohm. m)

L : backfill length (m)

D : backfill diameter (m)

- If several single vertical anodes are in parallel and each anode has its own backfill, the resistance of the groundbed can be calculated as follows:

Step 1: calculation of the single anode resistance to backfill

Ra = (**r** / (2 p * L)) * (Ln (8 *L / D) - 1)

Where:

Ra : Anode to backfill resistance (ohm)

r : Resistivity of the backfill (ohm. m)

L : Anode length (m)

D : Anode diameter (m)

Step 2: calculation of the backfill resistance to soil for a single anode

Rg = (**r** / (2 p * L)) * (Ln (8 *L / D) - 1)

Where:

Rg : backfill to soil resistance (ohm)

r : resistivity of the soil (ohm. m)

L : backfill length (m)

D : backfill diameter (m)

Step 3: calculation of the interference factor

f = 1 + ((2L/S) * Ln (0.656*N)/(Ln(8L/D)-1)).

Where:

L : backfill length (m)

N : number of anodes

S : distance between two anodes (m)

D : backfill diameter (m)

Step 4: Calculation of the final resistance

Rt = (Ra+ Rg) * f /N

- If several single vertical anodes are in parallel and all placed in a single continuous backfill (groundbed) the resistance can be calculated as follows:

Step 1: To use Sunde equation to calculated the resistance of N anodes to backfill

Rt = (r / (2 p *N* L)) * (Ln (8 *L / D) – 1 + (2L/S) * Ln (0.656*N)).

Where:

Rt : total resistance of N anodes (ohm)

r : resistivity of the backfill (ohm. m)

L : anode length (m)

D : anode diameter (m)

N: number of anodes

S: distance between two anodes (m)

Step 2: To calculate the groundbed (backfill) resistance to soil

Rg = (r / (2 p *L)) * (Ln (4 *L / d) + Ln (L/h) – 2 + (2h/L))

Where

Rg : backfill to soil resistance (ohm)

r : resistivity of the soil (ohm. m)

L : backfill length (m)

d : backfill diameter (m)

h: depth to the centre of groundbed (m)

Step 3: To calculate the final (anode to backfill + backfill to soil) resistance Rt :

Rf = Rt + Rg

Calculation of the horizontal shallow anode groundbed resistance without backfill:

- If several shallow horizontal anodes are laid in parallel in the soil without backfill, the resistance is to be calculated as follows:

$$Ra = (\rho / 2.\pi.L). [Ln \{(4L^2 + 4L \times \sqrt{(h^2 + L^2)}) / (d.h)\} + (h/L) - (\sqrt{(h^2 + L^2)} / L) - 1]$$

Where:

Ra: Individual anode resistance (Ω)

ρ: Resistivity of the soil (Ω.m)

L: Length of the anode (Ra)

d: Diameter of the anode (m)

h: Twice the depth of the centre line of the anodes (m)

The overall resistance Rt for N anodes is then:

$Rt = [(Ra \times f) / N]$

Where:

f: Anode interaction factor

N: Number of anodes

<u>Calculation of the horizontal shallow anode groundbed resistance with backfill:</u>

- If several shallow horizontal anodes are laid in parallel in a continuous backfill bed, the groundbed resistance is to be calculated as follows:

  <u>Step 1</u>: Calculation of the resistance for N anodes to the backfill

  $Ra = (\rho / 2.\pi.L). [Ln \{(4L^2 + 4L \times \sqrt{(h^2 + L^2)}) / (d.h)\} + (h/L) - (\sqrt{(h^2 + L^2)} / L) - 1]$

  Where:

  Ra: Individual anode resistance (Ω)

  ρ: Resistivity of the backfill (Ω.m)

  L: Length of the anode (Ra)

  d: Diameter of the anode (m)

  h: Twice the depth of the centre line of the anodes (m)

  The overall resistance Ro for N anodes is then:

  $Ro = [(Ra \times f) / N]$

  Where:

  f: Anode interaction factor

  N: Number of anodes

  <u>Step 2</u>: Calculation of the backfill resistance to soil

  $Rb = (\rho / 2.\pi.L). [Ln \{(4L^2 + 4L \times \sqrt{(h^2 + L^2)}) / (d.h)\} + (h/L) - (\sqrt{(h^2 + L^2)} / L) - 1]$

  Where:

  ρ: Resistivity of the soil (Ω.m)

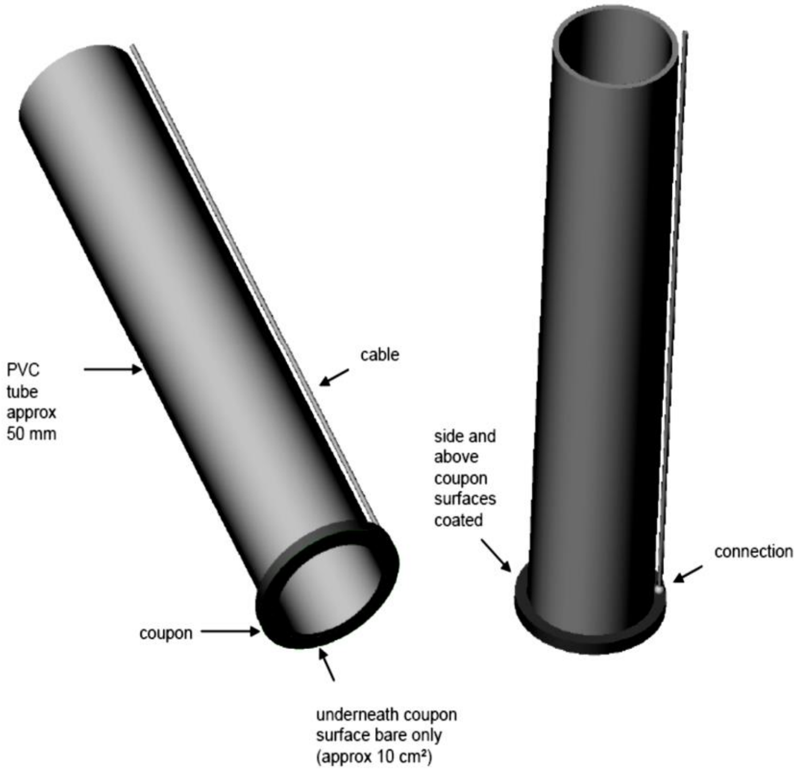
  L: Length of the backfill (m)

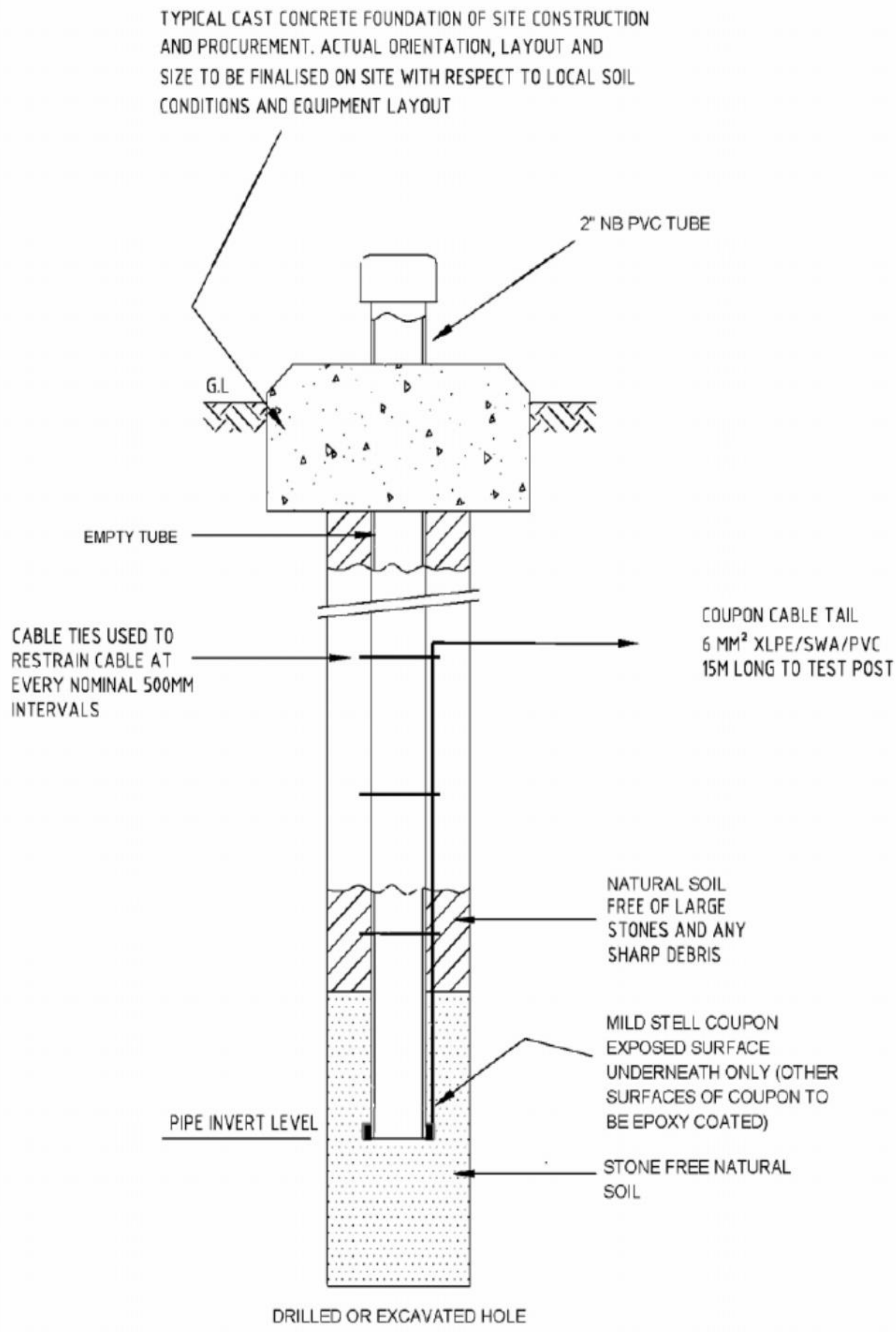
  d: Equivalent diameter of the backfill (m) h: Twice the depth of the centre line of the backfill (m)

Step 3: Calculation of the overall resistance of the groundbed

$Rt = Ro + Rb$

Appendix 2. Typical Coupon Assembly and Installation




TYPICAL CAST CONCRETE FOUNDATION OF SITE CONSTRUCTION AND PROCUREMENT. ACTUAL ORIENTATION, LAYOUT AND SIZE TO BE FINALISED ON SITE WITH RESPECT TO LOCAL SOIL CONDITIONS AND EQUIPMENT LAYOUT
2" NB PVC TUBE
G.L
EMPTY TUBE
CABLE TIES USED TO RESTRAIN CABLE AT EVERY NOMINAL 500MM INTERVALS
COUPON CABLE TAIL 6 MM² XLPE/SWA/PVC 15M LONG TO TEST POST
NATURAL SOIL FREE OF LARGE STONES AND ANY SHARP DEBRIS
MILD STELL COUPON EXPOSED SURFACE UNDERNEATH ONLY (OTHER SURFACES OF COUPON TO BE EPOXY COATED)
PIPE INVERT LEVEL
STONE FREE NATURAL SOIL
DRILLED OR EXCAVATED HOLE

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