PTT Exploration and Production Public Company Limited

PTTEP Engineering General Specification

(Engineering and Development Group)

Standard

Design of Cathodic Protection of Buried Pipelines

Document No: 10008-STD-6-COR-022-R00

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Revision History

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Old	New Document Refer : PEGS-12059-COR-022	04-Apr-16
R00	Revision note : New document code and formatting ***Item No./Clause*** — ***Description of Change*** All — Update document number and template align to PTTEP library standard	18-Sep-17

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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 pipelines against corrosion. It is to be used for the preparation of project specifications and as general guidelines by corrosion and inspection engineers either for future or existing pipelines installations.

3.0 SCOPE

This document defines the minimum requirements for design, installation, monitoring and commissioning of external cathodic protection of carbon steel buried pipelines (including their buried equipment such as valves, tees and anchoring flanges) and production flow lines between wellheads and treatment and/ or storage facilities.

This document does not apply to the protection of stainless steel pipelines, onshore treatment and/ or storage facilities, as well as intermediate pumping or compression stations.

Unless otherwise specified, the cathodic protection system will be designed for a service life of 20 years minimum.

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

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’
Inspector	The COMPANY’s representatives or members from company elected inspection bodies for the time being or from time to time duly appointed in writing by the COMPANY to act as its representatives for the purpose of the contract shall be referred to herein as the inspector.
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.
Purchase Order	The order issued by Purchaser consisting terms and Conditions and attachments thereto including but not limited to data sheets and drawings, specifications including referenced documentation therein, and all other documents and attachments
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:

CP	Cathodic protection
DC	Direct current
ERP	Electrical resistance probe
FBE	Fusion bonded epoxy
3LPE	Three layer polyethylene
3LPP	Three layer polypropylene
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-001, PEGS-12059-COR-001	External Anticorrosion Coatings for Pipelines
10008-STD-6-COR-002, PEGS-12059-COR-002	Field Joint Coating for Pipelines
10008-STD-6-COR-010, PEGS-12059-COR-010	Painting of Offshore and Coastal Structures and Facilities
10008-STD-6-COR-011, PEGS-12059-COR-011	Painting of Onshore Structures and Facilities
10008-STD-6-COR-023, PEGS-0842-COR-023	Design of Cathodic Protection of Onshore Facilities
10008-STD-6-COR-025, PEGS-12059-COR-025	Supply of Sacrificial Anodes for Cathodic Protection
10008-STD-6-COR-033, PEGS-12059-COR-033	Insulating joints

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
ISO 8501-1	Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness : Rust grades and preparation grades of uncoated steel substrates and steel substrates after overall removal of previous coatings
ISO 13623	Petroleum and natural gas industries - Pipeline transportation system
ISO 15589-1	Petroleum and natural gas industries – Cathodic protection for pipeline transportation systems
IEC 60529	Degree of Protection Provided by Enclosure (IP Code)

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
EN 13509	Cathodic protection measurement techniques
NACE SP 0177	Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems
NACE SP 0286	Electrical isolation of cathodically protected pipelines
NACE SP 0169	Control of external corrosion on underground or submerged metallic piping systems
NACE SP 0572	Design, installation, operation and maintenance of impressed current deep anode beds
BS EN 1591	Flanges and their joints: Design rules for gasketed circular flange connections - Calculation
BS EN 4515	Specification for welding of steel pipelines on land and offshore carbon steel and maganese steel pipelines

7.0 REQUIREMENTS FOR DESIGN OF CATHODIC PROTECTION OF BURIED PIPELINES

7.1 DESIGN SCOPE

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

7.1.1 SITE SURVEY

During a site survey, all relevant information/documents concerning the corrosivity of the environment (soil resistivity survey along the pipeline route, presence of active bacteria), the risk of deterioration of the pipe coating (rocks, tree roots), the presence of nearby metallic structures such as pipeline, rails etc. (whether cathodically protected or not) and their pipe-to-soil potentials, access points to the existing metallic structures, the presence of works 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, 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 eventually current requirement.

During site surveys, the risks of DC or AC stray currents or telluric currents shall be evaluated.

7.1.2 INFORMATION GATHERING

All documents and information concerning the route and the characteristics of the pipeline to be protected (diameter, length, material of construction, quality of the coating material, field joint coating and anything which is likely to influence the design of the cathodic protection system including the road, railroad, river crossing method, shall be collected.

7.1.3 STUDY

Detailed study shall be carried out and a report covering the following aspects shall be issued to the 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 subject pipeline.
- 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.
- Power supply requirement and type of power supply sources selected
- List of materials, including assembly accessories, and the corresponding technical specifications, schematic diagrams and detailed equipment diagrams
- List of possible suppliers.
- Detailed installation drawings, indicating the location of insulating joints, electrical bonding to be installed, layout of different types of equipment and their relevant installation procedures, wiring diagrams for electrical equipment.

Note: 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 that area shall be specified.

- Instructions proper for installations, indicating all precautions to be taken. Particular emphasis shall be placed on the construction of ground beds, connections on anode circuits, insulations between protected and non-protected parts, insulations between parts protected by different systems, remedial solutions to interferences between the pipeline to be protected and neighbouring buried metallic works, reference electrode installations at fixed points.

7.2 GENERAL REQUIREMENTS

7.2.1 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:

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

Non-certified personnel for CP design shall be subject to COMPANY approval on a case-by-case basis (demonstration of competence through detailed curriculum vitae and description of experience).

7.2.2 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, definitions of the systems to install, material supplies, checking and reception of equipment, and the commissioning on site. These shall be described with detailed procedures. All the calculations, systems, and materials that will be used shall be approved by the COMPANY.

7.2.3 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.

7.2.4 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, the COMPANY is responsible for transmitting 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, including the temporary and/or permanent rights of way to be acquired. However, the COMPANY is responsible for answering any question related to these matters. The COMPANY shall likewise deal with the acquisition of land and rights of way and settle all additional costs and compensation 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.

7.3 SPECIFIC REQUIREMENTS

7.3.1 PROTECTION CRITERIA

After polarization, the "instant –off" pipe-to-soil potential ("true" values after ohmic drop correction) of the carbon steel buried pipeline shall be:

- More negative than -850 mV/Cu/CuSO4 in aerated soil
- More negative than –950 mV/Cu/CuSO4 in environment with possible development of sulphate reducing bacteria (de-aerated soil with confirmation of active bacteria presence).
- For offshore or immersed in brackish water parts (if any), the measured potential of the pipeline must be more negative than -800 mV relative to Ag/AgCl reference electrode.
- Less negative than -1200mV/Cu/CuSO4 to avoid coating cathodic disbonding.
- For high soil resistivity (refer to ISO 15589-1), less negative than -750 mV/Cu/CuSO4 for 100Ω < ρ < 1000Ω and -650 mV/Cu/CuSO4 for ρ ≥1000Ω is acceptable.

The CP may have detrimental effects on some vulnerable 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 pipelines shall not be more negative than –1200 mV / Cu/CuSO4 electrode. For high strength steels (over 604 MPa SMYS), the instant-off pipe-to-soil potential shall not exceed –1100 mV / Cu CuSO4 electrode in aerated soils.

7.3.2 PIPELINE COATING

Please refer to 10008-STD-6-COR-001, PEGS-12059-COR-001 External Anticorrosion Coatings for Pipelines and 10008-STD-6-COR-002, PEGS-12059-COR-002 Field joint Coating for Pipelines

In order to reduce the corrosion risk, to reduce the current demand and to improve the current distribution along the pipeline, an anticorrosion coating is applied on the pipelines. However, the CP design depends not only on the external anticorrosion coatings (applied on the pipes in a plant and on the field joint during pipeline construction), but also on other kinds of coatings like joint in-fills, thermal insulation coatings and concrete coating.

The present specification is applicable to the 3LPP, 3LPE and FBE pipes coated in accordance with company specification 10008-STD-6-COR-001, PEGS-12059-COR-001(pipeline coating) and 10008-STD-6-COR-002, PEGS-12059-COR-002 (field joint coating).

Buried fittings such as sectioning valves shall be coated with a thick coating in accordance with 10008-STD-6-COR-011, PEGS-12059-COR-011.

7.3.3 SOIL RESISTIVITY MEASUREMENT

The Wenner method should preferably be used for the soil resistivity measurements. The soil resistivity shall be measured along the pipeline and at the pre-selected areas for anode groundbed installation.

If there are significant soil resistivity changes during the year, the survey shall be carried out during the dry season (or if possible, both dry and wet seasons for important and long pipelines).

7.3.3.1 ALONG THE PIPELINE ROUTE

Along the pipeline route, when using Wenner 4 pins Method, the distance (in meters) between two successive pins shall be defined as follows.

$a = 1.3 \times (C+\Phi)$

a = measurement depth

Where C is the average soil thickness in meters on top of the pipe (refer to project documents) and Φ is the pipe diameter in (m).

Measurements shall be carried out as follows:

- Every 1 or 2 kilometres according to the accessibility of the pipeline route.
- At crossings with existing pipelines, DC electrified railways, high voltage power lines and when there is a visible change in the nature of the soil at ground level.

7.3.3.2 AT LOCATIONS FOR IMPRESSED CURRENT ANODE GROUNDBEDS

At pre-selected locations for groundbeds, measurements have to be made at various depths depending on the type of groundbed selected.

For the shallow anode ground beds, the soil resistivity shall be measured at 80, 120 and 160 meters from the pipe, (no other metallic structure shall be present from the anodes at same distances). For the deep anode groundbeds, the soil resistivity shall be measured at 20, 30 and 40 meters from the pipe or any other metallic structure, (no other buried metallic structure shall be present at the same distances from the anodes).

7.3.3.3 RESULTS

The results shall be set out in the form of a table, specifying the place, kilometric position, and depth, corresponding resistivity value and any other observation concerning ground level. A profile of soil resistivity (Log $\rho = f(L)$) along the pipeline route shall be prepared.

7.3.4 ELECTRICAL INSULATION OF THE PIPELINE AND SAFETY DEVICES

The pipeline shall be electrically separated from other metallic structures by installing insulating joints or flanges (refer to 10008-STD-6-COR-033, PEGS-12059-COR-033).

These insulating systems shall be installed:

- where the pipeline is connected to steel casings (case of production flow line), intermediate stations comprising other metallic structures in contact with the soil, existing pipelines, and large metallic structures in contact with the ground, such as wells, intermediate stations and treatment or storage facilities
- at river, lake crossings (both sides), arrivals (or departures) of steel sealines onshore.

If electrical continuity with other metallic structures is required (for safety reasons) in case of over voltage /surge situations, an adapted solution to ensure the cathodic protection efficiency (polarization cell, surge arrester, isolating spark gaps or other) shall be submitted and approved by the COMPANY

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

7.3.4.1 INSULATING JOINTS

The number of insulating joints shall be limited as much as possible.

Normally the pipeline ends, including at intermediate stations and branching points and the interfaces with foreign cathodic protection by systems (if any), shall be fitted with an insulating joint of the monolithic or flanged type, depending on the fluid transported.

The type of insulating joint shall be submitted to the COMPANY for approval and shall satisfy the requirements of 10008-STD-6-COR-033, PEGS-12059-COR-033 and NACE SP 0286.

The insulating joints shall comply with the pipeline construction requirements and operating conditions: steel grade, transported effluent, pressure, temperature, etc.

During installation, particular attention shall be paid to avoid any short circuits that might be caused by electrical earthing network, electrical armoured cables, supports, walkway fittings (valve), personnel protection systems or any other metal structures, whether temporarily or permanently installed. Insulation joints shall be installed aboveground (or in a dry vault) and on straight pipe sections.

If the transported effluent contains free water, the monolithic insulation joints shall be internally coated as per 10008-STD-6-COR-033, PEGS-12059-COR-033 with glass flake filled vinylester coating (1 mm thick) for temperatures up to 120 degree C. In case of insulating flanges, the spools shall be internally coated on both sides of the flange along the length L, which depends on the aqueous electrolyte resistivity and the pipeline diameter:

$L = 400 \times D / \rho$

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.

7.3.4.2 SAFETY DEVICES

Wherever needed (frequent lightning and/or high voltage electrical transmission lines), the Contractor shall install safety devices, such as surge diverters or polarization cells, which shall remain operational without requiring constant checking.

The safety devices shall be in accordance with the recommendation in NACE SP 0177.

7.3.4.3 EARTHING CIRCUITS

In order to limit the current losses, the cathodic protection system shall be electrically isolated from earth circuits wherever needed. Nevertheless, some parts of equipment needing earthing for safety reason, such as electrically actuated valves cannot be economically isolated. In such a case, the earthing can be ensured with zinc anodes or galvanized steel cable, grounding resistance shall comply with the safety regulation.

7.3.5 DEALING WITH EXISTING METALLIC STRUCTURES AND HIGH VOLTAGE POWER LINES

Unless it is already available from the previous projects, all existing metallic structures (such as pipelines or railways), buried or in contact with soil, crossing or in parallel to the pipeline to be protected shall be identified and their owners shall be contacted:

- 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.

Unless otherwise indicated, only power lines with a voltage greater than or equal to 60 kV shall be taken into account. These include power lines crossing the pipeline route and parallel to the pipeline route within a strip of 500 m either side of the pipeline route. A site survey shall be carried out to collect the following information:

- Identification of pylons
- Nominal voltage between phases
- Pylon types and base dimensions at ground level
- Shortest distance from pylons to pipeline
- Presence of electrical interconnections between pylons (guard cable).
- Short-circuit power and maximum homopolar current in case of defect

7.3.6 TEMPORARY PROTECTION

Cathodic protection is generally installed several months (or even one year or more) after pipeline installation. Before this installation, temporary protection with sacrificial anodes may be required depending on the soil resistivity and should be designed separately.

The use of Mg anodes is recommended.

Current density for wet soil shall be 20 mA /m2, except when the actual value is available. The coating breakdown factors given in paragraph 5.4.1 shall be used. The soil resistivity for anode resistance calculations will be assumed a maximum of 30 ohm.m even if surrounding soil resistivity is higher. A partial polarisation, -100 mv shift, should be acceptable as long as the temporary protection should not trespass 6 months.

Note: In case of presence of stray currents special measures (temporary drainage) have to be taken to ensure that there is no positive pipe potential.

7.3.7 COMBINATION OF IMPRESSED CURRENT AND SACRIFICIAL ANODE CP SYSTEMS

If high resistivity soil is locally present along short section(s) of the pipe, cathodic protection by impressed current may not provide the necessary protection. Sacrificial magnesium anodes can be used locally, together with impressed current, to achieve the required protection level. Partial protection is acceptable, as per section 7.3.1 protection criteria here above.

This combination can also be used in case of local deficiency of CP protection level.

7.4 CATHODIC PROTECTION DESIGN METHODOLOGY

The design bases 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 principles:

- Amount of current provided by anodes at any time during the design life shall be sufficient to polarize the pipeline according to criteria given in paragraph 5.3.1 above.
- Weight of anodes shall be sufficient to provide necessary current up to the end of the design life.
- Unless justified by particular circumstances, any buried pipeline that requires cathodic protection must be electrically insulated from the other structures to which it may be connected.
- Over protection shall be avoided
- CP system shall not cause any interference to neighbouring structures and pipes.

Contractor shall prepare the calculation notes following the steps given below:

- Calculation of the total coated surface Sc and the bare surface to be protected Sp taking into account the coating breakdown factor.
- Definition of current densities Id for bare metal surfaces considering type of material and environment.
- 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 taking into account the actual weight, consumption rate (C) of the anodes to be used (sacrificial or impressed current types), 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).
- Calculation of anode, groundbed and cable resistances
- Sizing of DC sources

7.4.1 SURFACE TO BE PROTECTED

Pipelines are externally coated at least with an anticorrosion coating. The cathodic protection is implemented to protect the bare pipe surfaces at coating defects. For the calculation of the surface area to be protected, the coating breakdown factor (fc) is to be used. The coating breakdown factor is defined as the ratio of the current density required to polarize a coated metal surface (including defects) as compared to bare metal surface. It describes the anticipated reduction in cathodic current density due to the application of a coating. The fc values, regardless of the service life, are as follows:

- 3LPP and 3LPE coatings (typically 1.5 to 2.5 mm thick): 0.25 %
- FBE coating (typically 0.4 mm thick): 0.5 %
- Coal tar enamel (typically 2 to 4 mm thick): 5%

Bare surface areas to be protected Sp are to be calculated as follows:

- Sp = Sc x fc

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

7.4.2 CURRENT DENSITIES

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

- Steel in soil: 15 mA/m² dry and 30 mA/m² wet
- Copper in soil: 50 mA/m² dry and 80 mA/m² wet

Note: Copper is not a material currently used in oil and gas production/transportation except for electrical grounding in complex facilities.

- Concrete reinforcements: 1 mA/m² (for the surface of concrete in contact with soil)
- Steel covered of cement: 10 mA/m².

Dry soil means soil with a resistivity of minimum 10 Ohm.m.

7.4.3 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:

$I = Sc \times fc \times Id + \Sigma i$

Where;

- Sc is the total coated pipeline surface (including defects)
- Σi is the required current for polarization of the bare surfaces electrically in contact with the pipeline(copper , rebar, and other bare surfaces)
- Id is required current density for the bare surface

The current densities to be applied may change along the pipeline. If significant changes in the soil resistivity are observed, CP shall be designed for each pipeline section having different soil characteristics.

An alternative of calculation method for current demand as suggested in Standard ISO-15589-1 chapter 6 - 10 can be also followed.

7.4.4 ANODE NUMBER

Anode number is depending 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.

7.4.4.1 ANODE NUMBER BASED ON ANODE WEIGHT REQUIREMENT

The minimum total anode weight W (kg) to be installed in order to protect the pipeline or pipeline section 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: Anode 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

7.4.4.2 ANODE NUMBER BASED ON CURRENT OUTPUT CAPABILITY OF ANODES

Amount of current that can be produced by each anode is depending on the anode size (external surface) and anode material. For each material, there is a critical current density not to be exceeded. For example, for the silicon –iron chromium anodes, the maximum current density is 20 A/m^2. 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/m^2. For the practical and maximum current densities, the Contractor should refer to the anode Manufacturer data.

Typical maximum current densities for some anodes are as follows:

- Graphite: 10 A/m^2
- Fe-Si –Cr: 20 A/m^2
- MMO: 100 A/m^2

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

7.4.5 SIZING OF THE DIRECT CURRENT (DC) SYSTEM

7.4.5.1 NUMBER OF DC SOURCES

The number of DC sources distributed along the pipeline route is directly dependent on the average apparent electric characteristics of the pipeline at the end of the life span and the limiting potential criteria as defined in Section 7.3.1. The distance between two DC sources shall be calculated based on theoretical equations adapted for a pipeline of finite length, each section being considered to be laid in a uniform electrolyte and with uniformly distributed constant characteristics. As a general rule, the distance between two consecutive DC current sources shall be limited to 40 km for an impressed current system. For more 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.

7.4.5.2 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

1. I: Total required current (A)
2. R: Maximum overall resistance (Ω) calculated according to section 7.4.5.3
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.

7.4.5.3 CALCULATING OF OVERALL RESISTANCE

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

$R = R_{an} + R_{ca}$

Where:

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

Anode resistance

Unless otherwise stipulated, several "anode groundbed" configurations may be considered, depending on the dimensioning of the installation, the apparent resistivity of the ground at the selected point and the environment.Corresponding calculation formulas are given in APPENDIX 1.

Note that for several types of anode (such as Ti/Pt), anode resistance is limited by a maximum operating anode/electrolyte potential difference (refer to Manufacturer recommendations).

Cable resistance

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

$R_{ca} = \rho_o \times (l_c / s_c)$

Where:

- ρ_o: Resistivity of the cable core at 20°C (Ω.m), equal to 0.18 μ ohms.m for copper
- l_c: Length of cables considered (m), taking into account the loop shape of the cabling network of the groundbed,
- s_c: Cross-sectional area of the cable core (m^2)

Generally, the resistance of the cable per unit length for a specific diameter is provided by Cable Manufacturer documentation or various handbooks.

7.5 CP MONITORING DESIGN

CP monitoring on onshore pipes shall be carried out through CP test stations.

Test stations shall be provided along the pipeline route:

- At regular interval along the pipelines (3 km maximum)
- At road and rail crossings on both sides of the casing
- At foreign pipelines crossings
- Where pipelines run in parallel
- Where current circulating in the pipeline is to be measured
- At insulating joints
- At high voltage line crossing points with particular devices
- At all other points defined in the detailed study. In this case the frequency of the test points shall be determined in accordance with the following requirements:
- There shall be one current measurement station:

- Upstream and downstream from each impressed current source, except where an insulating joint electrically separates the two sections, or when there is only one section
- Between two impressed current sources 5/6 km apart
- At the junction between new and old or buried/underwater pipeline sections without insulating joint.

- There shall be one pipeline potential measurement station (test point) every 1 to 2 km for a normal route and 0.5 to 1 km for urban areas.
- There shall be one pipeline potential measurement station at critical points identified during the study. In this case, typical potential measuring station configuration is given by the sketch here below.

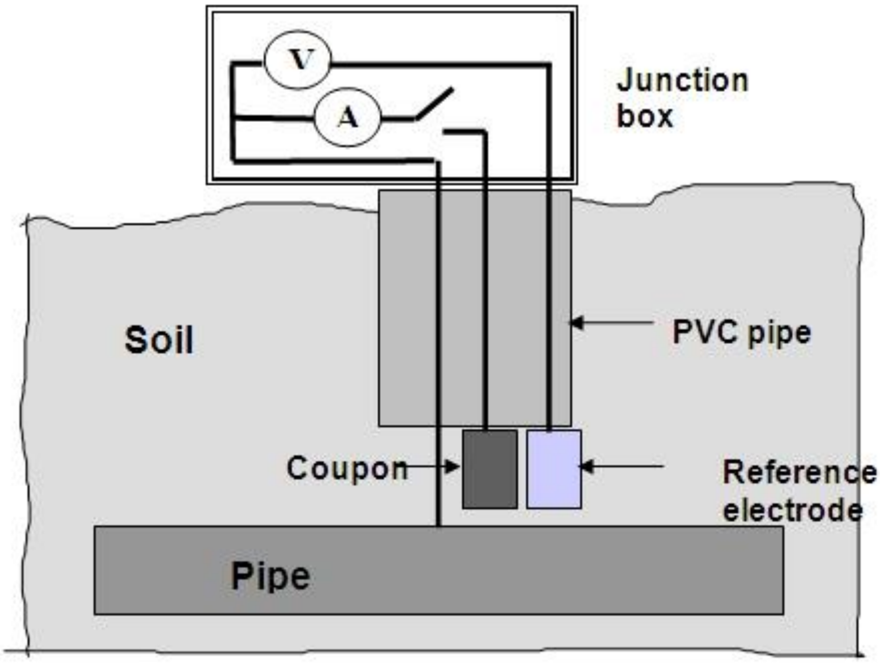

Figure 1 - CP Monitoring

- Permanent reference electrodes may be needed at other locations. The number and location of permanent reference electrodes shall be determined by the Contractor. However, one reference electrode shall be provided at each:
  - Impressed current source where stray currents are expected
  - Pipeline potential measurement stations at critical points
  - Test points, where the pipeline is buried more than 3 m deep
  - Test points in urban areas and when the surface is asphalted or concreted
  - Test points where the pipeline is weighted with concrete or protected by concrete slabs.

- Where appropriate, coupons allowing local ON/OFF measurements together with cathodic current density measurements shall be provided. This is especially required when stray or telluric currents have been identified.
- Wherever needed Electrical Resistance probes (ERP) can be installed for regular measurements of the corrosion rates. This is especially needed to evaluate the impact of telluric current on the pipeline integrity.
- Current test points shall be provided along the pipeline route every 10/15 km. The current test points shall comprise four cables connected to the pipe at 50 m intervals and brought to the test point in order to check the overall resistance of the pipeline so that the current draw needed for this section can be calculated.

7.6 POWER SUPPLY

When a low voltage power supply (220/240 V single phase or 380/440 V three-phase) is available at a reasonable distance (≤ 500 m), a transformer-rectifier set shall be used.

If there is no low voltage power supply, the DC source shall be self-powered. In this case the power can be supplied by gas thermo-generators (particularly on pipeline transporting dry gas that can be used for this purpose), or by solar panels and batteries. The power drawn shall be minimal, limiting the resistance of the circuit to 1 ohm.

For the set of gas thermo-generators, the capacity of the gas tanks shall be calculated for duration of:

- 5 consecutive days of shutdown, when the gas source is a gas pipeline
- 1 month between two refilling, when the gas is provided by an external source.

For solar powered units, the capacity of the sealed, maintenance-free batteries shall be rated for a minimum of five (5) consecutive days without sun.

The selection of self-powered DC source is subject to COMPANY approval.

7.7 EQUIPMENT SUPPLY

COMPANY Specification 10008-STD-6-COR-025, PEGS-12059-COR-025 shall be applied for supply of sacrificial anodes.

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

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

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

The Contractor shall provide the COMPANY with the following information for each item /piece of equipment:

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

7.7.1 TRANSFORMER / RECTIFIER

7.7.1.1 GENERAL CHARACTERISTICS

The transformer rectifier (T/R) shall comply with the safety regulations in force in the country of installation. Contractor shall prepare the data sheet to be submitted to COMPANY approval.

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 minimum 120% of 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 accepted on a case-by-case basis for a 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 T/R shall be equipped with a breaker allowing ON/OFF potential measurements. The types 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, a tap setting shall be avoided.

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

Upon specific request from the COMPANY, the T/R should be equipped with remote control and /or remote data collection.

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

- Inside the cubicle, with the insulated components avoiding 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 areas and accessible at all times. Minimum IP rating for indoor installation shall be IP31 (IEC 60529) for overall construction and shall consist of a dry type transformer. For outdoor installation, minimum IP55 (IEC 60529) applies.

7.7.1.2 TESTING

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

- 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.
- 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.

7.7.2 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, magnetite anodes can be used, depending on the soil characteristics, subject to COMPANY approval.

The alloy composition of Fe/Si anodes shall comply with BS 1591.

Table 1 – Alloy composition of anodes

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 ready for installation, delivered preconditioned or not in a backfill column (canister).

7.7.3 BACKFILL

The backfill comprises 99% grade petroleum coke breezes, 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.

For 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 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 case of geotextile bag, the ends of the bag shall be fitted with closing device (like “plastic collars” or other devices). On the cable entry side, the cable will do a tight loop inside the bag near to the closing device, to avoid possible damage of the 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.
- 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
- Visual and dimensional inspection certificate.

7.7.4 SACRIFICIAL ANODES

Sacrificial magnesium anodes may be used where soil resistivity is below 10 Ω.m or for temporary protection. Other sacrificial anodes (zinc and Al-In) are not used for the protection of buried pipes against corrosion. These 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. Note that zinc anodes may be used for special devices for the insulating joints protection and electrical earthing of polarized equipment as mentioned above (§5.3.4.3).

7.7.5 CABLES

All cables shall comply with the regulatory requirements and clearly identified by suitable labelling.

7.7.5.1 ANODE CABLES

The anodes may be connected either

- To the main anodic circuit or
- Individually and directly to the positive pole of the transformer-rectifier, or to a junction box.

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, and at most equal to the permitted limit.

7.7.5.2 MAIN CIRCUIT CABLES

These are cables between

- Anodes cables and the positive pole of the T/R unit (eventually through a junction box) for the positive DC current
- Structure and negative pole of the T/R unit (eventually through a junction box) for the negative DC current

The cables shall be single core, 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 16 mm2.

7.7.5.3 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.

7.7.5.4 MEASUREMENT CABLES

These cables are used to carry out the various cathodic protection measurements, independently of other link cables. Each conductor shall have a minimum cross-sectional area of 6 mm2. The nominal voltage allowed for these cables is 450/750 V.

7.7.6 JUNCTION BOXES

They shall provide a sufficient level of protection against shocks and the ingress of water. They are made 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. In hazardous areas, they shall comply with safety regulations. Generally, the following is requested:

- IP 55/IK 08 (IEC 60529) for outdoor locations
- IP 31 (IEC 60529) for indoor locations.

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.

7.7.7 MONITORING EQUIPMENT

7.7.7.1 TEST STATIONS

Outside urban areas, test points (see section 7.5) shall comprise:

- Junction box, as defined in Section 7.7.6, 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.
- 3" or 4" pipe made of rugged plastic or metal to support the junction box and protect the cables.

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 top of the pipe (tubular test station).

In all cases, the length of the pipe shall be at least 1.5 m.

Note: The test points may be used as kilometric pipeline markers, and shall then be constructed as such.

In urban areas, except within the fence and wall limit, these test points shall comprise a junction box placed inside a concrete pit or vault.

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

7.7.7.2 PERMANENT REFERENCE ELECTRODES AND COUPONS

The permanent reference electrode shall be $Cu/CuSO_4$. The electrolyte compound, comprising 1/3 bentonite and 2/3 copper sulphate 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 can also be used in state of $Cu/\ CuSO_4$ electrode.

7.7.7.3 COUPONS AND ER PROBES

Contractor shall propose all information about the coupons, ERP and reading /data storage equipment for COMPANY approval.

7.7.7.4 CURRENT TEST POINTS

Contractor shall provide necessary cables and equipment for current measurement on the pipe (see section 7.5).

7.8 INSTALLATION

7.8.1 TRANSFORMER RECTIFIER

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, it shall be located outside the perimeter of any hazardous areas 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.

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.

7.8.2 JUNCTION BOXES

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 ducts or trays used for fixing and protection purposes.

7.8.3 TEST POINTS

The test points shall be installed within the permanent right of way of the pipeline(s), at a fixed distance from the centre line and, if possible, on the same side, except perhaps for those close to insulating joints, inside a boundary limit and in urban areas.

In asphalted or concreted areas, regular access shall be provided to the natural soil for potential measurement near to or above the protected pipeline 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.

7.8.4 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.

7.8.4.1 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 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 groundbed and a test/junction box and, on the other side, between the protected structure and the same box.

7.8.4.2 CABLE CONNECTIONS TO THE PIPELINE

Direct welding of the cable to the pipe 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 pipe 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 aluminothermic welding method is applied, a fully qualified procedure shall be required in accordance with BS 4515 and the relevant welding pipeline 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 suitable mastic, such as cold cure epoxy. The surface shall be brushed clean prior to coating to grade of cleanliness ST 2 as specified in ISO 8501-1.

The cable shall not be wound around the pipeline. Extra 0.5 m long cable shall be available around the cable connection.

7.8.4.3 PERMANENT REFERENCE ELECTRODES AND COUPONS

Before use, the permanent $Cu/CuSO_4$ 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 stable 72 hours after its total immersion.

Coupons shall be installed as close as possible to the pipe (no more than 10 cm from the surface of the pipeline) and to the reference electrode. Coupon and permanent reference electrodes shall be positioned either above the centre line of the pipe or on the side at mid-axis 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 ($Cu/CuSO_4$ or calomel) positioned nearby.

7.8.5 ANODES

7.8.5.1 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 2 – 3 m from the either side of the pipeline and at 1 m depth minimum. They shall normally be laid horizontally in the bottom of the trench. The trench shall be perfectly backfilled after installation.

7.8.5.2 IMPRESSED CURRENT ANODES

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

- Availability of energy source
- Soil resistivity: anodes shall be installed in low resistivity soil
- Non- hazardous area
- Excavator access availability
- Distance from the protected pipeline and other buried structures: shallow anodes shall be at least 80 meters away from the nearest metallic structures and anodes. Anodes installed in deep wells 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.
- Land occupation of the anodic groundbed: a detailed study shall define the land occupation of the anodic groundbed, 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 groundbed 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 RP 0572 shall apply.

7.9 COMMISSIONING

A detailed schedule for commissioning, drawn up by the Contractor, 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 pipeline and its surface installations.

A COMPANY representative shall attend all the phases of the commissioning.

The Contractor shall ensure the training of the COMPANY personnel in charge of the operation of the CP system, preferably during the commissioning phase.

7.9.1 NATURAL POTENTIAL MEASUREMENT AND START UP OF CP SYSTEM

Following procedure shall be used.

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

- To 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
- To measure the natural potential of the pipeline and all connected structures (En), to be protected or not, at all test points. Prior to carrying out this work, temporary protection (if any) shall be disconnected several days ahead.

Then 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:

- Checking the power supply voltage and DC output voltage (Uo) off-load (0 to 100%)
- Powering up and measuring 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 the CP system along the pipeline, to connect them to the pipeline and set the variable resistor, if any, to zero, to measure the current output, to set the variable resistor maximum value and to measure the current again. To measure also pipeline potential during the current measurement operations).
- Adjustment of each impressed current DC source to obtain the minimum protection level all along the pipeline 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.

7.9.2 MEASUREMENTS AFTER POLARISATION

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

The balance of the current on each anode shall be verified and adjusted to ensure an equal consumption of the anodes.

After the measurements at minimum setting (section 7.9.1, 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 upper limit, resulting in a 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.

Nevertheless, in the case of pipeline, if the lower limit is exceeded in some part and it is needed to obtain the minimum level of protection in other part, it means that the design is not satisfying and re-enforcement of the system (usually additional CP station) is required.

7.9.3 INVESTIGATION AND ELIMINATION OF INTERFERENCES

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

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

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

Stray currents (if any) influence shall be located, identified, quantified by appropriate recording and mitigated up to an acceptable level by adequate means (resistance or polarized interconnections, controlled drainage systems, etc.).

7.9.4 VALIDATION

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

If the protection level is not adequate, the 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.

7.10 TECHNICAL FILE

The detailed technical file shall be approved by the COMPANY. This information shall be handover to the COMPANY. It shall at least comprise:

- Characteristics of the pipes
- 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
- Detailed as built drawings/ wiring plans providing all details about installation
- Impressed current station with groundbeds details, location and means of access
- List of test points with their characteristics, precise location and means of access
- Stray current influence recorded charts before and after correction
- Operating and maintenance instructions and operating procedures
- Cathodic protection potentials obtained during the commissioning including the natural potentials.
- Initial adjustment of the DC sources
- Equipment list with references and Vendor's' addresses
- List of spare parts for two years of operation, with complete references

- 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.
- 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. Groundbed Resistance Calculation

1) Calculation of the vertical anode resistance without backfill:

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

   Ra = (ρ/(2ρ*L)) * (ln(8 *L/D) - 1)

   Ra: Anode resistance (ohm)

   ρ: Resistivity of the environment (ohm. m)

   L: Anode length (m)

   D: Anode diameter (m)

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

   Ra = (ρ/(2π*L)) * (ln(4*L/D) - 1)

   c) 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

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

   Rt = (ρ/(2π *N* L)) * (ln(8*L/D) – 1 + (2L/S) * ln(0.656*N)).

2) Calculation of the vertical anode resistance with backfill:

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

   Step 1: calculation of the single anode resistance to backfill

   Ra = (ρ/(2π *L)) * (ln(8*L/D) - 1)

Where:

Ra:	Anode to backfill resistance (ohm)
ρ:	Resistivity of the backfill (ohm. m)
L:	Anode length (m)
D:	Anode diameter (m)

Step 2: calculation of the backfill resistance to soil

$Rg = (\rho/(2\pi*L)) * (\ln(8*L/D) - 1)$

Where:

Rg:	Backfill to soil resistance (ohm)
ρ:	Resistivity of the soil (ohm. m)
L:	Backfill length (m)
D:	Backfill diameter (m)

b) 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

$Ra = (\rho/(2\pi*L)) * (\ln(8*L/D) - 1)$

Where:

Ra:	Anode to backfill resistance (ohm)
ρ:	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

$Rg = (\rho/(2\pi*L)) * (\ln(8*L/D) - 1)$

Where:

Rg:	Backfill to soil resistance (ohm)
ρ:	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

$Rt = (Ra+Rg) * f / N$

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

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

$Rt = (\rho/(2\pi*N*L)) * (\ln(8*L/D) – 1 + (2L/S) * \ln(0.656*N))$.

Where:

Rt: Total resistance of N anodes (ohm)

ρ: 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

$Rg = (\rho/(2\pi*L)) * (\ln(4*L/d + \ln(L/h) – 2 + (2h/L))$

Rg: Backfill to soil resistance (ohm)

ρ: 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:

$Rf = Rt + Rg$

3) Calculation of the horizontal shallow anode groundbed resistance without backfill:

a) 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:	Is number of anodes

4) Calculation of the horizontal shallow anode groundbed resistance with backfill:

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

Step 1: 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:	Is number of anodes

Step 2: 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

$Rt = Ro + Rb$

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