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ADNOC

ADNOC GROUP PROJECTS AND ENGINEERING

CATHODIC PROTECTION SPECIFICATION

Specification

AGES-SP-07-001

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شركة بترول أبوظبي الوطنية
Abu Dhabi National Oil Company

GROUP PROJECTS & ENGINEERING / PT&CS DIRECTORATE

CUSTODIAN	Group Projects & Engineering / PT&CS
ADNOC	Specification applicable to ADNOC & ADNOC Group Companies

Group Projects & Engineering is the owner of this Specification and responsible for its custody, maintenance and periodic update.

In addition, Group Projects & Engineering is responsible for communication and distribution of any changes to this Specification and its version control.

This specification will be reviewed and updated in case of any changes affecting the activities described in this document.

INTER-RELATIONSHIPS AND STAKEHOLDERS

a) The following are inter-relationships for implementation of this Specification:

   i. ADNOC Upstream and ADNOC Downstream Directorates and

   ii. ADNOC Onshore, ADNOC Offshore, ADNOC Sour Gas, ADNOG Gas Processing. ADNOC LNG, ADNOC Refining, ADNOC Fertilisers, Borouge, Al Dhafra Petroleum, Al Yasat

b) The following are stakeholders for the purpose of this Specification:

   ADNOC PT&CS Directorate.

c) This Specification has been approved by the ADNOC PT&CS is to be implemented by each ADNOC Group company included above subject to and in accordance with their Delegation of Authority and other governance-related processes in order to ensure compliance

d) Each ADNOC Group company must establish/nominate a Technical Authority responsible for compliance with this Specification.

DEFINED TERMS / ABBREVIATIONS / REFERENCES

"**ADNOC**" means Abu Dhabi National Oil Company.

"**ADNOC Group**" means ADNOC together with each company in which ADNOC, directly or indirectly, controls fifty percent (50%) or more of the share capital.

"**Approving Authority**" means the decision-making body or employee with the required authority to approve Policies & Procedures or any changes to it.

"**Business Line Directorates**" or "**BLD**" means a directorate of ADNOC which is responsible for one or more Group Companies reporting to, or operating within the same line of business as, such directorate.

"**Business Support Directorates and Functions**" or "**Non- BLD**" means all the ADNOC functions and the remaining directorates, which are not ADNOC Business Line Directorates.

"**CEO**" means chief executive officer.

"**Group Company**" means any company within the ADNOC Group other than ADNOC.

"Specification" means this Cathodic Protection Specification.

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General

1 PURPOSE

1.1 Introduction

This specification defines the minimum requirements for the design of Cathodic Protection (CP) systems for ADNOC assets.

As per COMPANY policy, cathodic protection is applied to all buried steel structures and structures in contact with an electrolyte.

The following steel structures shall normally require cathodic protection and are covered under this standard:

- Buried onshore transmission pipelines
- Buried in-plant piping network
- Above ground storage tanks (AST)
- Buried tanks/vessels
- Buried sections of normally A/G flowlines
- Pipeline casings
- Offshore structures
- Offshore pipelines
- Jetties & sea water intakes
- Reinforced concrete
- Semi buried critical concrete reinforced structures
- Well casings

All activities associated with cathodic protection design shall be agreed and approved by the designated relevant Technical Authority within ADNOC and/or ADNOC nominated CONSULTANT / CONTRACTOR.

1.2 Objective of this Specification

This Specification shall be referred to in relevant Project documentation issued to the Consultants in the design of such facilities.

This Specification also serves to specify required interfaces with Electrical and Mechanical Engineering requirements.

The Specification is intended for use by relevant COMPANY staff in Engineering, Operations and Supply as well as by COMPANY nominated CONTRACTORS, SUPPLIERS / MANUFACTURERS and Inspection Agencies.

2 SCOPE

This document covers the minimum requirements for site surveys, design installation, commissioning and hand over of temporary and permanent cathodic protection systems for the structures detailed in sec.1.1.

Selection of type of Cathodic Protection System

Permanent Cathodic Protection of buried or submerged surfaces shall in most instances be Impressed Current Cathodic Protection (ICCP) Systems. Sacrificial CP system shall be employed for offshore structures and pipelines, as well as a temporary system for buried pipelines and in-plant piping networks during construction. For short buried sections of the pipelines or isolated vessels, where an ICCP system may not be feasible, a sacrificial CP system may be employed. However, the application of a sacrificial CP system shall be justified and approved by COMPANY).

Cathodic protection of the internal surfaces of hydrocarbon containing tanks or vessels, with a continuous water layer, shall be by sacrificial anodes.

For tanks which do not contain hydrocarbons (e.g. Fire Water Tanks, Potable Water Tanks) cathodic protection of the internal surfaces shall be achieved using either impressed current or sacrificial anodes. The selection of the particular system shall be advised by the COMPANY.

For potable water tanks only magnesium anodes shall be considered if a sacrificial CP system is being employed for corrosion protection.

Note:

As permanent CP (ICCP) system can take considerable time to implement, a temporary sacrificial CP system shall be provided to protect buried pipelines during the construction and prior to commissioning of the ICCP system. All sections of the buried pipeline shall be protected with a temporary CP system within two weeks of burial of the pipeline. For in plant piping where the construction period is more than 6 months temporary sacrificial CP system shall be provided. All sacrificial anodes shall be disconnected prior to the energization of the permanent CP system.

3 DEFINED TERMS / ABBREVIATIONS / REFERENCES

Glossary	
Anode	The electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution.)
Anode Bed / Groundbed	The system of buried or submerged electrodes, to conduct the required current into and through the electrolyte to the steel surface to be protected.

Backfill	Low resistivity material placed around the anodes to reduce the resistance and have uniform environment around the anode
Bracelet Anodes	Anode with geometry suitable for direct attachment around circumference of a pipeline. These may be half-shell bracelet consisting of two semi-circular sections or segmented bracelet consisting of a large number of individual anodes.
Cathode	The electrode of an electrochemical cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit.)
Cathodic Polarization	(1) The change of electrode potential caused by a cathodic current flowing across the electrode/electrolyte interface. (2) A forced active (negative) shift in electrode potential
Cathodic Protection (CP)	A technique to reduce the corrosion rate of a metal surface by making that surface the cathode of an electrochemical cell.
Coating Disbondment	The loss of adhesion between a coating and the substrate.
Continuity Bond	A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity
Corrosion	The deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment.
Corrosion Probe	An electrical resistance instrument that determines the corrosion rate on its metal electrode or electrodes by measuring and converting the measurements to metal loss.
Corrosion Rate	The time rate of change of corrosion. (It is typically expressed as mass loss per unit area per unit time, penetration per unit time, etc.)
Current	The amount of electric charge flowing past a specified circuit point per unit time, measured in the direction of net transport of positive charges. (In a metallic conductor, this is the opposite direction of the electron flow.)
Current Density	The electric current flowing to or from a unit area of an electrode surface.

Deep Anode Bed	One or more anodes installed vertically at a nominal depth of 15 m or more below the earth's surface in a drilled hole for the purpose of supplying cathodic protection current.
Diode	A bipolar semiconducting device having a low resistance in one direction and a high resistance in the other
Direct Current (DC) Decoupling Device	A device used in electrical circuits that allows the flow of alternating current in both directions and stops or substantially reduces the flow of direct current.
Dissimilar Metals	Different metals that could form an anode-cathode relationship in an electrolyte when connected by an electron-conducting (usually metallic) path.
Electrical Interference	Difference in potential between the anode and the steel structure.
Electrical Isolation	Any electrical disturbance on a metallic structure in contact with an electrolyte caused by stray current(s).
Electrochemical Cell	The condition of being electrically separated from other metallic structures or the environment.
Electrode	An electrochemical system consisting of an anode and a cathode in metallic contact and immersed in an electrolyte. (The anode and cathode may be different metals or dissimilar areas on the same metal surface.)
Electrolyte	A material that conducts electrons is used to establish contact with an electrolyte, and through which current is transferred to or from an electrolyte.
Foreign Structure	A chemical substance containing ions that migrate in an electric field.
Galvanic/ Sacrificial Anode	Any metallic structure that is not intended as a part of a system under cathodic protection**.**
Galvanic Corrosion	A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.
Galvanic Couple	Accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.
Impressed Current	A pair of dissimilar conductors, commonly metals, in electrical contact in an electrolyte.

Impressed Current Anode	An electrode, suitable for use as an anode when connected to a source of impressed current. (It is often composed of a substantially inert material that conducts by oxidation of the electrolyte and, for this reason, is not corroded appreciably.)
Isolating joint	A joint or coupling installed between two lengths of pipes in order to provide electrical discontinuity between them.
Jumper	Jumper is a resistive circuit comprising of wires, variable resistor (to control the flow of current) and shunt (to monitor the current flow). It is provided to facilitate the controlled flow of current across IJ thus preventing the internal corrosion caused by jumping of current inside the IJ in the presence of low resistivity conductive fluid
Microbiologically Influenced Corrosion (MIC)	Corrosion affected by the presence or activity, or both, of microorganisms.
Midpoint	The point on a pipeline between two cathodic protection stations where the influence of the two cathodic protection stations is expected to be equal and the protection levels are usually lowest.
Natural potential	The structure or pipeline to electrolyte potential measured when no cathodic protection is applied and polarization caused by cathodic protection is absent.
“OFF" potential or Instantaneous “OFF” Potential	The structure or pipe to electrolyte potential measured immediately after the cathodic protection system is switched off and the applied electrical current stops flowing to the structure or pipeline surface, but before polarization of the structure or pipeline has decreased.
"ON" potential	The structure or pipeline to electrolyte potential measured while the cathodic protection system is continuously operating.
Pipeline	The pipeline or pipelines with associated equipment as defined in the scope of the cathodic protection design contract
Pipe to soil potential	The difference in electrochemical potential between a pipeline or foreign structure/pipeline and a specified reference electrode in contact with the electrolyte. Similar terms such as structure to soil potential, pipe to electrolyte

	potential, pipe to (sea) water potential are sometimes used as applicable in the particular context.
Polarization	The change from the corrosion potential as a result of current flow across the electrode / electrolyte interface.
Polarized Potential	The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.
Rectifier	A device for converting alternating current to direct current.
Reference Electrode	An electrode having a stable and reproducible potential, which is used in the measurement of other electrode potentials.
Resistivity	The electrical resistance between opposite faces of a unit cube of material.
Resistor	An electrical device that limits the quantity of electricity flowing in an electrical circuit by resisting the flow of current through it.
Sacrificial Protection	Reduction of corrosion of a metal in an electrolyte by electrically connecting the metal to a galvanic anode (a form of cathodic protection).
Shallow Groundbed	One or more anodes installed either vertically or horizontally at a nominal depth of less than 15 m (50 feet) for the purpose of supplying cathodic protection current.
Shielding	Preventing or diverting cathodic protection current from its natural path.
Shunt	A precise resistor with known resistance in an electrical circuit used to measure a voltage drop. The measured voltage drop is used to calculate the amount of current flowing in that electrical circuit.
Stray Current	Current flowing through paths other than the intended circuit.
Stray-Current Corrosion	Corrosion resulting from stray current.
Voltage	An electromotive force or a difference in electrode potentials expressed in volts.
Voltage Drop	The voltage across a resistance when current is applied in accordance with Ohm’s law.

Abbreviations	
3LPE	Three layer polyethylene
3LPP	Three layer polypropylene
°C	Degree centigrade
µm	Microns
AC	Alternating current
Ag/AgCl or ssc	Silver / Silver Chloride
A/G	Above ground
AST	Above ground storage tank
CAT	Cold applied tape
CBF	Coating breakdown factor
CIPS	Close interval potential survey
CP	Cathodic protection
CPET	Corrosion protection evaluation tool
CPP	Casing potential profile
CTE	Coal tar epoxy
$Cu/CuSO_4$ or cse	Copper / Copper Sulfate (copper sulfate electrode)
Cu/XLPE/PVC	Copper / Crosslinked polyethylene / Polyvinyl chloride
DC	Direct current
DCVG	Direct current voltage gradient
DFT	Dry film thickness
DSS / SS	Duplex stainless steel / stainless steel
EPC	Engineering - procurement – construction
EPDM	Ethyl propylene diene monomer

ESP	Electric submersible pumps
FBE	Fusion bonded epoxy
FEED	Front end engineering design
GS	Galvanised steel
HC	Hydrocarbon
HDPE	High density polyethylene
HLL	High liquid level
HMWPE	High molecular weight polyethylene
HSS	Heat shrink sleeve
HVAC	High voltage alternating current
ICCP	Impressed current cathodic protection
IJ / IF	Isolating joint / insulated flange
ITP	Inspection & test plan
km	kilometre
KV	Kilovolts
LLL	Low liquid level
LOI	Letter of intent
m	metre
mA/m^2	Milliamps per square metre
MMO	Mixed metal oxide
MnO_2	Manganese dioxide
mV	millivolts
NDB	Negative distribution box
NJB	Negative junction box
OHL / OHPL	Over head (power) line

PCR	Polarisation cell replacement
PE	Polyethylene
PL	Pipeline
PP	Polypropylene
ppm	Parts per million
PU	Polyurethane
PVDF	Poly vinylidene fluoride
RDX	Road crossing
RE	Reference electrode
ROV	Remotely operated vehicle
SACP	Sacrificial anode cathodic protection
SiFeCr	Silicon iron chrome
sqm	Square metre
SRB	Sulfate reducing bacteria
TBC	To be confirmed
Ti	Titanium
TR	Transformer rectifier
UAE	United Arab Emirates
UPVC	Unplasticized polyvinyl chloride

4 NORMATIVE REFERENCES

International Code(s) and Standards

ASTM C778	Standard specification for standard sand
ASTM G57	Test method for Field measurements of soil resistivity using Wenner four pin method

BS EN ISO 12696	Cathodic Protection of Steel in Concrete
DNVGL-RP-B401	Cathodic protection design
DNVGL-RP-F103	Cathodic Protection of submarine pipelines by galvanic anodes
EN 12496	Galvanic anodes for cathodic protection in seawater and saline mud
EN 12696-1	Cathodic Protection of Steel in Concrete
EN 13174	Cathodic protection for harbour installations
EN 18086	Corrosion of metals and alloys - Determination of AC corrosion - Protection criteria
ISO 15257	Cathodic protection. Competence levels of cathodic protection persons. Basis for certification scheme
ISO 15589-1	Petroleum, petrochemical and natural gas industries - Cathodic protection of pipeline systems - Part 1: On-land pipelines
ISO 15589-2	Petroleum, petrochemical and natural gas industries - Cathodic protection of pipeline systems - Part 2: Offshore pipelines
NACE Corrosion Paper 2107	What you need to know about MMO coated metal anodes
NACE SP0104	The Use of Coupons for Cathodic Protection Monitoring Applications
NACE SP0169	Control of External Corrosion on Undergroun or Submerged Metallic Piping Systems
NACE SP0177	Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems
NACE SP-0187	Design Considerations for Corrosion Control of Reinforcing Steel in Concrete
NACE SP0196	Galvanic anode cathodic protection of internal submerged surfaces of steel water storage tanks
NACE SP0207	Performing Vlose-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines

NACE SP0285	External Corrosion Control of Underground Storage Tank Systems by Cathodic Protection
NACE SP0286	Electrical isolation of cathodically protected pipelines
NACE SP0290	Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures
NACE SP0388	Impressed current cathodic protection of internal submerged surfaces of carbon steel water storage tanks
NACE SP0408	Cathodic Protection of Reinforcing Steel in Buried or Submerged Concrete Structures
NACE SP0572	Desig, Installation, Operation and Maintenance of Impressed Current Deep Anode Beds
NACE SP0575	Internal cathodic protection (CP) systems in oil-treating vessels
NACE TM0101	Measurement Techniques Related to Criteria for Cathodic Protection of Underground Storage Tank Systems
NACE TM0102	Measurement of Protective Coating Electrical Conductance on Underground Pipelines
NACE TM0497	Measurement Techniques Related to Criteria for Cathodic Protection on Submerged Metallic Piping Systems

SECTION A

5 REFERENCE DOCUMENTS

5.1 ADNOC Specifications

None

5.2 Standard Drawings

None

5.3 Other References (Other Codes/IOC Standards) etc.

None

6 DOCUMENTS PRECEDENCE

The specifications and codes referred to in this specification shall, unless stated otherwise, be the latest approved issue at the time of Purchase Order placement.

It shall be the CONTRACTOR 'S responsibility to be, or to become, knowledgeable of the requirements of the referenced Codes and Standards.

The CONTRACTOR shall notify the COMPANY of any apparent conflict between this specification, the related data sheets, the Codes and Standards and any other specifications noted herein.

Resolution and/or interpretation precedence shall be obtained from the COMPANY in writing before proceeding with the design/manufacture.

In case of conflict, the order of document precedence shall be:

UAE Statutory requirements

ADNOC Codes of Practice

Equipment datasheets and drawings

Project Specifications and standard drawings

Company Specifications

National/International Standards

7 SPECIFICATION DEVIATION/CONCESSION CONTROL

Deviations from this specification are only acceptable where the MANUFACTURER has listed in his quotation the requirements he cannot, or does not wish to comply with, and the COMPANY/CONTRACTOR has accepted in writing the deviations before the order is placed.

In the absence of a list of deviations, it will be assumed that the MANUFACTURER complies fully with this specification.

Any technical deviations to the Purchase Order and its attachments including, but not limited to, the Data Sheets and Narrative Specifications shall be sought by the VENDOR only through Concession Request Format. Concession requests require CONTRACTOR'S and COMPANY'S review/approval, prior to the proposed technical changes being implemented. Technical changes implemented prior to COMPANY approval are subject to rejection.

8 CATHODIC PROTECTION CONTRACTOR QUALIFICATION

The cathodic protection systems shall be carried out by a professional and experienced cathodic protection engineering CONTRACTOR / Consultant approved by the COMPANY and meeting project specific requirements in accordance with ISO 15257 or NACE.

9 QUALITY ASSURANCE

Contractor shall plan establish, implement, and maintain a Quality system for the Engineering, Procurement, Construction and Pre-commissioning of the project.

A Project specific Quality Plan shall be prepared specifically for the project describing the application of the corporate Quality System to the works, and any extension or adaptation necessary to meet the specified contract requirements. Although reference to, and appropriate parts of Contractors Corporate Quality Manual and Procedures can be utilized, the submission of the Corporate Quality Manual as substitute for a Contract specific Project Quality Plan will not be recognized as fulfilling the project quality plan requirement. A specific Project Quality Plan shall be submitted by Contractor and shall be subject to approval by Company. It is CP Consultant's responsibility to ensure the execution of an ADNOC approved Project QA / QC plan.

The CP Consultant shall bring to the attention of ADNOC any requirements of the project documentation which in their opinion are not in accordance with good engineering practices, or otherwise not suitable for the intended service, or areas where potential cost savings could be made without prejudicing operability, availability and maintainability.

In the event of conflict between statutory requirements, project documentation, ADNOC standards, international Codes and Standards, the Company shall be intimated by Consultant / Contractor. The more onerous and more stringent requirements in such a conflict shall be deemed to apply, unless there is formal agreement by the Company to the contrary.

The CP Consultant shall clearly state every exception to the requirements of the project documentation to which the equipment shall be manufactured and tested. If no exceptions are stated, then full conformity shall be assumed and required.

All components shall be procured from ADNOC approved manufacturers. In case of any item not included in ADNOC vendor list, special approval shall be obtained from ADNOC before supply. No deviation is acceptable in this regard.

10 SAFETY

The CONTRACTOR shall be responsible for safety of personnel, equipment and the environment. The installation and operating procedures shall ensure safe working practices. All relevant requirements of the UAE and ADNOC Health, Safety and Environment (HSE) procedure manual shall be met. The CONTRACTOR shall be familiar with local safety rules and practices and implement these in the work.

All surveys, construction, installation and commissioning activities shall comply with ADNOC PTW system /ADNOC HSE Manual.Design Basis

11 ENGINEERING REQUIREMENTS - GENERAL

For new construction projects, the design of the cathodic protection system shall be an integral part of the total construction project design. Electrical isolation (where applicable) and a suitable coating system shall be provided for the project structure design.

To achieve an effective cathodic protection design for a structure, a site survey shall be performed to collect essential information on soil resistivity, geographical factors, the likelihood or the existence of stray currents. For pipeline systems, the important features along the pipeline route, that can have an impact on the CP system, shall be recorded during the site survey.

For offshore pipelines / structures, where a site survey is impracticable, geographical factors such as sea temperature / resistivity and sea bed conditions shall be ascertained from project oceanographic survey data.

When designing a cathodic protection system for retrofitting to an existing structure certain repairs and modifications to the structure may be necessary to comply with these specifications. Other requirements may have to be determined by site investigations.

The cathodic protection system shall be designed so that any external/ internal (as applicable) corrosion on the intended structure is eliminated and any adverse stray current effects on the project structure / pipeline or on foreign structures / pipelines is avoided.

Cathodic protection effectiveness surveys shall be performed during pre-commissioning stages of the CP system

12 BASIC INFORMATION FOR CP DESIGN

CONTRACTOR shall collect all the information required to carry out the cathodic protection design.

This information, as a minimum, shall include:

(a) Detailed information on the structure to be protected (length, diameter, height, structure material, wall thickness)

(b) Operating temperature of the structure / internal product, Product composition

(c) Structure Coating and Field joint coating (for pipelines)

(d) Required design life of the cathodic protection system. This design life shall be equal to or exceed the design life of the structure being protected

(e) Scope limits

(f) Relevant drawings (pipeline route, existing systems, foreign structures / pipelines, pipeline/ road crossings, Overhead AC power lines, valves, topographic details)

(g) Applicable environmental and operating conditions for the cathodic protection equipment

(h) Details of existing adjacent CP systems, results of any interference data

(i) AC power supply availability

(j) Electrolyte conditions (soil resistivity, pH, bacteria, chlorides, sulphates, sulphides)

Primary structure data shall be defined during Project Concept and FEED stages. Contractor shall conduct site survey to gather complete information.

13 SITE SURVEYS

Before the design of a cathodic protection system for a pipeline / structure is made a pre-design site survey shall be carried out.

Information obtained during previous surveys for a proposed pipeline route may be used provided that the data, conditions and source of such surveys are included in the survey report.

If the area to be surveyed is affected by seasonal changes, these shall be taken into account. If possible a survey shall be carried out during different seasonal conditions and the most severe conditions shall be used considered for the design.

Structures for which site surveys may be impractical i.e. offshore structures, jetties / sea water intakes, , data shall be taken from project basis of designs, oceanographic surveys or the data proposed within this standard (where applicable).

The following items are an essential part of such a survey, particularly for a pipeline, buried piping or vessel design:

13.1 General Terrain Description

The survey shall include general information of the terrain along the pipeline route and general information for the structures including the following:

(a) Limits of the structures to be protected and CP isolation points

(b) Type of terrain and vegetation (urban areas, industrial areas, farm lands, forests, open fields, desert, swamps, rocks)

(c) Visible relevant features and crossings (main roads, overhead power lines, other pipelines)

(d) Foreign installations and existing CP facilities in close proximity

(e) Location of available power sources which can be utilized to energize TR units

(f) Suitable locations for impressed current CP systems and anode groundbeds

(g) All other information that is considered relevant to the design of a cathodic protection system

13.2 Soil Resistivity Measurements

Average Soil resistivity measurements shall be carried out along the route of the pipeline at a regular interval of 1 km. For short pipelines, the span could be further reduced to 500 m. For buried piping within the plants, soil resistivity shall be recorded at reduced spacing of approximately 50 m depending upon the size of the plant and presence of buried pipelines. Additional measurements shall be carried out where there are visual changes in soil characteristics.

At each location one measurement shall be carried out at pipe depth. Additional measurements shall be recorded at higher depths notably at crossings (road, track, fence) as required, which can be used for calculating resistance of sacrificial anodes. General norm is to record resistivity at 1, 2 and 3 m depth.

For other structures such as vessels the soil resistivity shall be measured in all the four directions around the vessel and at the structure installation depth (top, middle and bottom) and proposed anode installation depth.

For each type of soil, readings should be taken in at least two different locations. At each location a minimum of 2 measurements shall be carried out.

Acceptable methods for soil resistivity measurements are:

(a) Four terminal resistivity method (Wenner)

(b) Two terminal resistivity method (Shepard)

(c) Soil sample (soil box) resistivity method (for Above Grade tanks)

(d) Geonics method (EM-31, EM-34)

When the soil resistivity measurements are used to locate suitable places for surface groundbeds, the four terminal method shall be used to determine the resistivity at depths shallower than 10 m.

For deep anodebeds Geonics EM-34 shall be used. Soil Resistivity meters having higher voltage such as Terrameter / Syscal may also be used for measuring soil resistivity using Wenner method.

13.3 Soil Investigation

Chemical and bacterial soil analysis shall be carried out. Testing requirement is also applicable for imported backfill used for pipeline construction. Testing requirements shall be advised by the COMPANY for specific project based on site conditions.

Testing of SRB is mandatory for Sabkha areas and low lying areas where water logging is expected.

13.4 Current Drainage Tests

When designing a cathodic protection system for existing pipelines / structures a current drainage test shall be performed by the CONTRACTOR to determine the current requirement and optimal current distribution. This may necessitate temporary installation of one or more groundbeds and DC power sources (e.g. batteries or portable rectifiers), timer-units, and test facilities to the pipeline / structure under investigation.

To obtain relevant results, pipeline isolation equipment and monitoring facilities should be installed before current drainage tests are carried out.

The required current is determined when, after full polarization is achieved, the "OFF" potentials measured at regular points along the pipeline / at the structure are within the protection criteria as given in Table 1. This current demand shall further be adjusted to allow for expected further deterioration of the coating during the remaining life of the pipeline.

If the pipeline / structure has been previously cathodically protected, historical data may be used to determine the current demand.

Note: Higher value of current as per the current drain test or calculated design current shall be used for designing the CP system.

13.5 E-Log I survey

E-Log I surveys shall be undertaken to determine the current requirements for the protection of onshore well casings.

E Log I curves developed from the survey shall be obtained on at least one, or preferably more, of each type of casing completion, on a similar terrain, for the given field.

13.6 CPET/CPP surveys

Cathodic Protection Evaluation Tool (CPET) or Corrosion Protection Profile Tool (CPPT) surveys shall be undertaken on well casings to determine the level of protection being afforded by the operational CP system and to identify unprotected areas along the well casing.

It shall be ensured that the well casings are allowed to polarise for a minimum of one (1) week after energising and commissioning of the CP system, before running a CPET/CPPT survey.

Running a CPET/CPPT survey is an expense activity not only because of the means involved but also because running them represents a loss in production, as it requires removal of the production tubing.

Such activities must be co-ordinated closely with COMPANY to determine the most appropriate time for execution.

14 DETAILED DESIGN

The CONTRACTOR shall submit to the COMPANY a cathodic protection detailed design for review and approval which shall include the documentation listed under section 14.2.

The detailed design shall contain all information required for the procurement of cathodic protection equipment and for the construction, commissioning, and handover of the cathodic protection system.

Design of a correctly sized and located cathodic protection system is vital to achieving the protection criteria and required design life.

14.1 Selection of Cathodic Protection System

For the cathodic protection of land based buried structures an impressed current system is preferred. ICCP is also the preferred protection system for near shore structures e.g. jetties / sea water intakes.

For offshore structures / pipelines, sacrificial anode CP system using Al-Zn-In anodes shall be adopted. .

The type of cathodic protection system to be applied (i.e. sacrificial anodes or impressed current) shall be advised by the COMPANY. If not specified, the CONTRACTOR shall select the type of cathodic protection and shall justify his choice in his basic design.

The following factors should be considered when making the selection.

(a) Soil resistivity

(b) Total current demand

(c) Type of coating

(d) Economic considerations

(e) Presence of stray currents

(f) Availability of power supply

(g) Site layout

(h) Presence of other structures

(i) Size of the structure to be protected

(j) Maintenance requirements

(k) Possibility to use existing COMPANY owned cathodic protection systems

If the above factors do not clearly justify one particular system, impressed current shall be used.

If the land based pipeline under protection may be influenced by stray currents, impressed current shall be applied.

Note: In some cases (e.g. on large projects) the COMPANY may request the CONTRACTOR to carry out a basic design / Front End Engineering Design (FEED) prior to commencement of detailed design.

14.2 Design Documents

The design documents shall be submitted by the CONTRACTOR to the COMPANY for approval, covering the following minimum requirements:

(a) Results of any site surveys and soil investigations that have been carried out

(b) Results of any current drain tests that have been carried out for retrofitting on existing pipelines

(c) Any requirements for modifications to existing pipeline systems such as electrical separation or coating repair

(d) Specify type and location of CP isolation

(e) Justification of the selected cathodic protection system and anode materials if the choice is made by the Contractor

(f) Temporary cathodic protection system for pipelines

(g) Calculations of current requirement as per operating temperature, type of coating, pipeline current attenuation, location, type and capacity of proposed CP stations, resistance and current output of groundbeds, rating of DC power source

(h) DC and AC interference testing and mitigation

(i) A summary of the used formulae and standards

(j) A schematic diagram of the proposed cathodic protection system

(k) A list of the estimated number and types of cathodic protection monitoring facilities

(l) Details of DC cable connections to protected / foreign structures

(m) Identify cable routes and specify type, size and lengths of AC and DC cables

(n) The civil works required to install the cathodic protection system. Such works include transformer/rectifier plinths, deep well head works, mounting details of distribution boxes and test posts, cable trenches, security fencing, etc.

(o) Any other information that is regarded by the CONTRACTOR as essential for cathodic protection design

(p) A schedule of materials including a complete set of material and equipment specifications

(q) A complete set of design drawings

(r) Installation procedures

(s) Commissioning procedures

(t) Operation and Maintenance instructions

(u) CP Commissioning Report

The detailed design documents shall be submitted to the COMPANY for approval before construction starts.

15 MATERIAL SCHEDULES

A complete schedule of materials to be used for the installation of the cathodic protection system is required to demonstrate that all materials to be procured are in accordance with this specification. This schedule shall include the required quantities and grades of all materials to construct the cathodic protection system and the proposed manufacturers and suppliers.

The data sheets for the CP equipment shall be submitted by CP CONTRACTOR / VENDOR to the COMPANY for review and approval. The procurement shall commence once the data sheets have been approved by the COMPANY.

At the time of material delivery, the CONTRACTOR shall supply the original test certificates issued by the MANUFACTURER for the major CP materials. These shall, as a minimum, cover anodes, carbonaceous backfill, DC power source, cables and reference cells.

The CONTRACTOR shall also include a list of proposed tools and spare parts required for maintenance of the system during the first two (2) years of operation.

Colour coding for cables shall be strictly as per COMPANY standards.

Note: Detailed Material specifications are covered under Appendix 1 of this document and same shall be followed by contractor.

16 INSTALLATION PROCEDURES

Full construction details and installation procedures of the cathodic protection system are required to ensure that the system shall be installed in accordance with this specification.

These shall include:

(a) Written procedures for the installation of all features and components of the CP system particular to the structure to be protected; onshore pipelines/piping, well casings, offshore structures/pipelines, jetties/sea water intakes etc, including (but not limited to) CP current sources, groundbeds, cables, test facilities and all civil works, procedures for cable connections to the structure

(b) A time schedule for the installation of the system, where required in relation to the construction schedule of the structure

(c) Written procedures of all tests required to demonstrate the specified quality of installation

(d) All relevant construction drawings including but not limited to plot plans, locations of cathodic protection stations and test facilities, cable routing, single line schematics, wiring diagrams, groundbed construction and civil works, hazardous area as applicable

(e) Inspection and Test Plan (ITP)

(f) Project Quality Plan, Operation and maintenance instructions

(g) Written procedures to ensure safe working practices during the installation and operation of the cathodic protection system

The installation of the cathodic protection system shall start only after approval of the installation procedures by the COMPANY.

17 PRE-COMMISSIONING TESTING AND INSPECTION

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all CP equipment particular to the structure to be protected: onshore pipelines/piping, well casings, offshore structures/pipelines, jetties/sea water intakes etc.

Such tests shall include (where applicable); trial operation of dc power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to earth tests of new groundbed anodes and zinc earthing electrodes, current flows from sacrificial anode systems (where possible), calibration checks of permanent reference electrodes, testing of electrical isolation. Specialised surveys for onshore pipeline coating inspection survey, using D.C voltage gradient technique (i.e. DCVG).

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

18 COMMISSIONING PROCEDURES

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design.

These shall be written specific to the structure to be protected, including: onshore pipelines/piping, well casings, offshore structures/pipelines, jetties/sea water intakes.

This document shall include as a minimum and where appropriate for the particular structure:

(a) Procedures for the testing of pipeline / structure isolation

(b) Procedures for natural potential surveys

(c) Procedures for energizing cathodic protection hardware

(d) Procedure for testing and adjustment of structure-to-electrolyte potential

(e) Requirements for polarization of the pipeline / structure

(f) Procedures for full ON / OFF potential surveys

(g) Procedures for interference testing

(h) Close Interval Potential Survey (CIPS) - applicable onshore pipelines only

(i) Procedure for mitigation measures if interference is detected during the commissioning (if the positive swing on the foreign structure exceeds 20 mV)

(j) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the pipeline / structure

(k) Required format of the commissioning report

(l) Procedure for clearing the Punch List items

19 OPERATING AND MAINTENANCE MANUAL

An operating and maintenance manual (O&M Manual) is required to ensure that the cathodic protection system is well documented and that operating and maintenance procedures are available for the future operator.

This document shall contain:

(a) A description of the system and system components

(b) Protection potential criteria for the system

(c) Pre-commissioning and commissioning results

(d) As built drawings

(e) Manufacturer documentation

(f) A schedule of all monitoring facilities

(g) Monitoring schedules and requirements for monitoring equipment

(h) Monitoring procedures for each of the types of monitoring facilities installed on the protected structures

(i) Guidelines for the safe operation of the cathodic protection system

(j) General guidelines for trouble shooting of CP equipment

(k) Spare parts list for major CP equipment

20 TRAINING

CONTRACTOR shall include the presence of COMPANY operating personnel during installation, pre-commissioning, commissioning, CIPS, DCVG and any other surveys as applicable for handing over the cathodic protection systems. The CONTRACTOR shall provide training to COMPANY personnel in the operation and maintenance of the cathodic protection system with particular attention being paid to any special features of the system and troubleshooting.

SECTION B

21 TECHNICAL REQUIREMENTS – BURIED ONSHORE PIPELINES

21.1 General

The CP design for buried onshore pipelines shall be based on a permanent impressed current system designed in general accordance with the requirements of ISO 15589-1.

Temporary protection of buried onshore pipelines shall also be provided, based on a sacrificial anode system.

The section buried onshore pipelines, covers design criteria, parameters and calculations of cathodic protection systems used for buried flowlines, inter station pipelines and transmission lines.

21.2 CP Criteria

The pipeline to soil potential is the criterion for evaluating effectiveness of cathodic protection.

Impressed current CP systems shall be designed such that instantaneous “OFF” / Polarised potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the pipeline, over its design life, to achieve an Instant “OFF” / Polarised potential over the entire pipeline, equal to or more negative than stated in Table 1 below. To avoid detrimental effects on the applied coating (disbondment) or on the structure (hydrogen induced stress cracking) due to over protection, Instant “OFF” / Polarised potentials for carbon steel shall not be more negative than the overprotection limit value as stated in Table 1 below.

Some corrosion resistant steels and high strength steels (e.g. Duplex stainless steels) are more susceptible to hydrogen induced stress cracking than carbon steel. The protection criteria for structures made of such materials shall be determined on a case by case basis. This is also applicable when designing a cathodic protection system for a pipeline crossing or approaching another pipeline made of such a material.

The protection potential values stated for aerobic environments shall also apply to anaerobic environments where soil investigation has confirmed the presence of active sulphate reducing bacteria.

In addition, these protection potential values shall also apply to high temperature effects where operating temperatures greater than 60°C are encountered.

Table 1 — Buried Onshore Pipelines - Protection Criteria for ICCP Systems

ENVIRONMENT	Instantaneous "OFF" / Polarised Potentials, mV w.r.t		
	$Cu/CuSO_4$	Ag/AgCl	$Zn/ZnSO_4$
Protection potential for steel in aerobic/anaerobic soil environment.	-950	-900	+150
Over protection limit for carbon steel in soil / water environment	-1200	-1150	- 100
Over protection limit for Duplex Stainless Steel (DSS) / SS	-1100	-1050	0

Notes.

(i) Cu/CuSO4 reference cell is used for pipelines in normal soil where chloride content is low

(ii) Ag/AgCl reference cell is used in soils having high chloride content (more than 1000 ppm)

(iii) Zn/ZnSO4 reference cell is used in soils applications for special monitoring purposes only

(iv) 100 mV polarization criteria may be considered (subject to acceptance by COMPANY) in special cases if it is not possible to achieve the potentials listed in Table 1

(v) 'NATIVE' potentials, for pipelines not under the influence of a cathodic protection system and/or stray interference effects, shall be considered as approx. -500mVcse

(vi) 'AS-FOUND' potentials shall be applied to pipelines already indicating potentials of -950mVcse or more negative as a result of interference / influence from other (existing) cathodic protection systems, prior to commissioning of the pipeline dedicated CP system. In such events, COMPANY shall be advised and further investigation shall be required to determine the cause of the excessive negative potentials

(vii) For sacrificial CP system ON potential values as per Table 1 above shall be considered.

(viii) For sacrificial CP system where 'AS-FOUND' potential of flowline is already -950 mVcse or more negative due to interference or influence of other CP systems, protection criteria from the installed CP system shall result in a net flow of current to the pipeline and a negative polarization observed-

21.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for pipeline CP systems, based on the different CP systems applied, shall be as follows:

- Permanent ICCP system — 30 years,
- Permanent SACP system — 20 years,

- Temporary SACP system – 2 years

Note.

(i) If the normal life of components of the cathodic protection system is shorter than the design life of the equipment or if adequate control of the cathodic protection levels at the beginning and at the end of the design life are technically incompatible, the CONTRACTOR shall include, and justify in CP design, the installation of a system based on this shorter life and shall include methods and instructions for future upgrading of the system.

This may be the case with sacrificial anode systems and battery operated cathodic protection systems or solar generators.

(ii) Sacrificial CP system based on magnesium anodes, generally have an operating life expectancy of upto 10years. Where magnesium anodes are used for permanent SACP systems, measures shall be incorporated for anode replacement after 10 years to ensure the required 20 year design life is achieved.

21.4 Anode/Groundbed Parameters

21.4.1 Anodes

Anodes for use in the protection of buried onshore pipelines shall be as follows:

- Mixed metal oxide (MMO) coated titanium tubes (ICCP)
- Magnesium alloy anodes (SACP)
- Zinc alloy anodes (SACP)

The MMO/titanium anode shall have the following design parameters:

Table 2 – Buried Onshore Pipelines - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters	Design Values
Anode size (min)	25mm dia. X 1000mm long
Titanium	ASTM B338, grade 1
Current density (in carbonaceous backfill)	Max. 50 A/m^2
Current density (in calcined petroleum)	Max. 100 A/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly.

The magnesium alloy anode shall have the following design parameters:

Table 3 — Buried Onshore Pipelines - Magnesium Alloy Anode Design Parameters

Magnesium alloy parameters	Design Values	
	Std potential	Hi-potential
Anode solution potential	-1500 to -1550mVcse	-1750 to -1770mVcse
Electrochemical capacity	1100 A-hr/kg	1100 A-hr/kg
Anode density	$1.94 g/cm^3$	$1.94 g/cm^3$
Efficiency	50%	50%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Appendix 1 for details)

(iii) Efficiency values based on an anode current density of approx. $320 mA/m^2$

(iv) Details of anode chemical composition given in Appendix 1

(v) Magnesium anodes should not be used if the resistivity of the electrolyte is higher than 15,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met

The zinc alloy anode (ASTM B418 Type II) shall have the following design parameters:

Table 4 — Buried Onshore Pipelines - Zinc Alloy Anode Design Parameters

Zinc alloy parameters	Design Values
Anode solution potential	-1100mVcse
Electrochemical capacity	738 A-hr/kg
Anode density	$7.00 g/cm^3$
Efficiency	90%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Appendix 1 for details)

(iii) Details of anode chemical composition given in Appendix 1

(iv) Zinc anodes should not be used if the resistivity of the electrolyte is higher than 1,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met.

21.4.2 Groundbeds

A series of dedicated CP stations/groundbeds distributed along the length of the pipeline shall be used to provide current.

Distances between neighbouring stations shall be based on current attenuation calculations with due consideration for local variations in terrain & geology. The attenuation calculations shall be based on the coating of the pipeline, pipeline diameter, wall thickness and the material of the pipeline. The lowest thickness of the pipeline shall be used for attenuation calculations.

Groundbeds shall be designed to have a resistance to remote earth of less than 1.0 ohm and to fulfil anode current output characteristics under normal soil conditions.

The resistance of groundbed shall be limited to 0.6 ohm when solar power unit is being used as the DC power source (up to 20 Amps). The resistance of groundbed shall be limited to 0.3 ohm for DC output between 20-40 Amps). This is to limit the solar power voltage to 12 V.

For very deep borehole groundbeds (>100m) data on nearby groundbeds and water table depth may be used to design new groundbeds. In such cases, data and design shall be subject to COMPANY confirmation and approval.

The active column of the deep anodebed shall be 10m below the static water table.

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system
- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- Its location is remote from the pipeline and any other buried structure, to provide a regular distribution of current along the pipeline (not applicable for close anode systems, either onshore or in seawater environment)
- Groundbed shall not be installed immediately below high tension overhead transmission lines
- The risk of causing harmful interference on other buried structures is minimized
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

The selection of the location and the type of groundbed shall depend on local conditions such as:

- Soil conditions and resistivity at various depths
- Strong seasonal changes in surface soil conditions
- Available terrain (for surface groundbeds)
- Risk of shielding (specially for parallel pipelines)
- Risk of damage by excavation (surface groundbeds)

Note:

(i) The number of groundbeds shall be equal to or exceed the number of power supply sources at each location.

(ii) Shallow groundbeds shall not be used.

Sacrificial CP systems shall be used for the temporary protection of buried pipelines during the construction stage and until the permanent CP system is energized.

The design of a sacrificial anode cathodic protection system shall be based on the anode current and weight meeting the design requirements.

The design current shall be calculated based on the surface area, design current density at the operating temperature and current allowance. Anode weight shall be calculated based on design current, design life, anode alloy capacity, and efficiency and utilization factor.

The anode current output shall be calculated based on driving voltage and total circuit resistance. Current output shall be more than the design current. It may be necessary to increase the number of anodes to meet the design current output.

21.5 Design Resistivity

Design resistivity values shall be based on the soil resistivity measurements recorded during pre-design site surveys.

21.6 Design Current Density

The CONTRACTOR shall carry out pipeline attenuation calculations to determine the spacing between cathodic protection stations as required during the pipeline design life.

The current densities in Table 5 and average coating resistances in Table 6 shall be used as minimum design values for new construction projects and are to be related to the total pipeline surface area. The current density values take into account coating deterioration during the design life of the pipeline.

It is assumed that pipeline construction is carried out in a manner to avoid coating damage during construction and operation.

To determine the current requirement for existing pipelines without CP, where the actual condition of the applied coating is unknown, a current drainage test shall be carried out. The cathodic protection system capacity shall be determined as the higher of the two values determined by the current drainage survey and above calculations.

Table 5 — Buried Onshore Pipelines - Design Current Densities for Different Pipeline Coatings

Type of coating	Current density for 'initial' design mA/m²	Current density for 'final' design mA/m²
3LPE or 3LPP	0.001	0.05
FBE	0.02	0.4
Liquid epoxy Coal tar or bituminous coating	0.2	0.8

Notes.

(i) Values derived from ISO 15589-1:2015 Table 3.

(ii) Initial current density values are based on the minimum 'optimized' design values and are applicable for the design of sacrificial anodes for temporary CP systems.

(iii) Final current density values are based on the minimum 'conservative' design values and are applicable to the design of impressed current systems for long term operation.

(iv) The values given in Table 5 account for the pipelines operating at not more than 30°C temperatures. Where pipeline operating temperatures exceed 30°C a temperature correction factor shall be applied: current density value shall be increased by 25% for each 10°C rise in operating temperature above 30°C.

Table 6 — Buried Onshore Pipelines - Average Coating Resistance for Different Pipeline Coatings

Type of coating	Average coating resistance for 'initial' design Ohm.m²	Average coating resistance for 'final' design Ohm.m²
3LPE or 3LPP	450,000	30,000
FBE	22,500	9,000
Liquid epoxy Coal tar or bituminous coating	2,250	5,000
Steel Resistivity	0.18 micro-ohm.m	

Notes.

(i) Average coating resistance values for 'initial' design derived from Formula (6) of ISO 15589-1:2015.

(ii) Potential shift (ΔE) used in formula based on 0.45V, i.e. -0.95Vcse - (-)0.5Vcse. Current density values used in formula as that depicted in Table 6 above.

(iii) Average coating resistance values for 'final' design based on ADNOC operational experience.

21.7 Coating Breakdown Factor

Current density values detailed in Table 5 include for coating deterioration during the design life of the pipeline. Application of additional coating breakdown factors are therefore not required.

21.8 Surface Area

Surface area of the pipeline to be afforded cathodic protection shall be based on the total buried pipeline surface area.

21.9 Monitoring Facilities

21.9.1 Cable Connection to Pipeline

The cable connection to the pipeline shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to pipeline and structure.

Cable connections shall not be carried out on bends or within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All below grade cable connections shall be fully encapsulated to comply with the original coating standards. A holiday test shall be conducted before backfilling.

The following methods shall be used for cable connections:

Table 7 — Buried Onshore Pipelines - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Existing Pipeline / Piping	Welded Pad Note i	Pin Brazing Note ii
New Pipeline / Piping	Welded Pad	Welded Pad Note ii

Notes.

(i) A welded pad is preferred for current carrying cables. In case it is not possible to use a welded pad connection to the existing pipeline, pin brazing connection may be allowed. The connection shall be done by an experienced and approved welder / operator.

(ii) The cable shall be looped around the pipe to avoid damage to the connections by accidental pulling of the cable.

21.9.2 Monitoring Facility Types

Regular monitoring of cathodic protection systems is vital to maintaining the design life integrity of the structure. This section specifies the minimum requirements for the different types of monitoring facilities required for buried pipeline cathodic protection systems.

(a) Potential Monitoring

Combined potential monitoring test posts / distance markers shall be installed at 1 km intervals along the pipeline route, unless the position of this test post coincides or is in close proximity (± 100m) to another type of test point.

(b) Isolating Joint / Insulated Flange

In addition to monitoring, the test facility shall have a provision to by-pass the current through an external resistor. A suitably rated shunt shall also be provided to monitor the flow of current through an external circuit.

(c) Drain Point

A test station shall be installed at every drain point connection.

It shall also have a buried coupon to facilitate measurement of "OFF" potentials. It shall be provided with a permanent reference cell. Alternatively a combined coupon and permanent reference cell shall be used.

(d) Buried Cathodic Protection Coupons

Coupon test facilities shall be installed at each drain point, the mid-points between all drain points and at a regular interval of 5km.

For smaller pipelines, less than 5km long, a coupon test facility shall be installed at the farthest point from the drain point.

Coupon test facility shall be provided with a permanent reference cell. Alternatively a combined coupon and permanent reference cell shall be used.

(e) Line Current Measurement

A four wire line current measurement test facilities shall be installed at a chainage of 1km and thereafter at a regular interval of 10km.

(f) Foreign Service Bonding

Foreign Service test facilities shall be installed at all Foreign Service crossings.

Where one or more foreign pipelines parallel the protected line with a separation of less than 50m, test facilities complete with bond boxes shall be installed at the beginning of the parallelism, end of parallelism and at 10km intervals.

Note: In case of parallel pipelines, one additional test post shall be provided at existing ADNOC onshore pipeline to facilitate potential monitoring. It will have two potential monitoring cables.

(g) Uncased Road Crossings

At each black top road crossing, a monitoring test post shall be installed on the downstream side. For roads having a width of more than 10m, two monitoring test posts, one at each side shall be provided.

(h) Cased Crossings

Where a pipeline is cased, for example at road crossings, then cased crossing test facilities shall be installed.

It shall allow for monitor the pipe-to-soil potential of the carrier as well as the casing pipe.

Where a casing is less than 10m in length a single test facility at one end of the casing is required. For casings of length 10m or greater, test facilities shall be installed at each end of the casing.

(i) OHL Crossings

At each OHL crossing, pipe shall be grounded using a Zinc grounding cell and solid state polarisation.

21.10 Interference

Buried pipelines can be subject to DC / AC interference.

21.10.1 DC Interference

CP systems of adjacent structures can interfere with the protected structure.

DC interference can lead to accelerated corrosion of affected structure.

The CONTRACTOR shall investigate possible sources of detrimental DC stray currents and include proposals in the design on how to mitigate the effect of such stray currents on the protected structure.

CONTRACTOR shall carry out a stray current survey at the time of commissioning.

For interaction effects on secondary structures as a result of the CP system on the protected structure, the following shall be applied:

(a) On secondary structures without a CP system, maximum positive potential change on any part of the secondary structure, resulting from interaction, should not exceed 20 mV. In case a positive swing of more than 20 mV, mitigation measures shall be adopted by the CONTRACTOR

(b) On secondary structures with a CP system, unacceptable interference shall be deemed when the 'Polarized' potential on the secondary structure does not achieve the protection potential range as per Table 1

Mitigation measures include:

(a) Prevention of pickup of stray current by improved isolation or shielding

(b) Re-distribution of CP current sources, adjustment of current output from mutually interfering CP power sources

(c) Installation of metallic bonds between affected structures

(d) Application of unidirectional control devices such as diodes or reverse current switches

(e) Use of galvanic anodes on the anodic section

DC interference is not considered an issue for: tank/vessel internals, offshore pipelines/structures (with SACP system), short buried sections of surface flowlines or pipeline casings at RDX (with SACP system)

21.10.2 AC Interference

AC interference is caused by high voltage AC transmission systems. This predominantly affects buried pipeline systems where the AC transmission systems can parallel the pipeline for long distances.

The main risks associated with AC interference can be listed as follows:

(a) AC induced voltages can be hazardous to personnel carrying out monitoring and maintenance of affected structures

(b) Induced AC currents can affect CP systems. It can lead to increased DC potentials on the line, making the control and monitoring of the CP systems difficult and may possibly damage TR components and pipeline coating

(c) Very high transient voltages can occur during fault conditions, e.g. lightning strikes or phase imbalance, which present a hazard to personnel and may damage the pipeline coating

(d) Can lead to AC induced corrosion in the buried pipelines

As a minimum, following details of high voltage ac power line, which can be a primary source of ac interference, shall be collected:

(a) Length of parallel power line

(b) Locations where power line route diverges, minimum and maximum distance between pipeline and ac power line

(c) Number and angle of power line and pipeline crossings

(d) AC voltage

(e) AC Current

(f) AC Fault current

(g) Types of AC power line supports (wooden / metallic), Grounding of metallic pylons.

(h) Design of the poles and dimensions between cables

(i) Soil Resistivity along pipeline route

(j) Pipeline Coating quality

(k) Details of CP stations, Block Valve stations in the affected sections

Mitigation measures to prevent AC interference shall be submitted by the CONTRACTOR to COMPANY whenever the conditions stated in Table 8 are cumulatively met.

Interference from AC powerlines shall be simulated on a computer considering all data related to AC powerline, pipeline/flowline and soil properties and an interference study shall be submitted to the COMPANY.

Table 8 — Buried Onshore Pipelines - Conditions for AC Interference Studies

OHPL rating (KV)	PL /OHPL separation (m)	Min parallel length (m)
33	≤15	500
66	≤100	500
≥132	≤500	500

Mitigation measures shall be included whenever the following conditions are exceeded:

(i) Maximum step and touch voltage shall be limited in accordance with international or local safety requirements at all locations where personnel can touch pipeline / pipeline components. As per NACE SP-0177 and/or EN 18086, steady state touch voltage limit is 15 V

(ii) Current density limits as per EN 18086 shall apply: AC current density lower than 30A/sqm (on a 1sqcm coupon probe) and DC current density lower than 1A/sqm (on a 1sqcm probe)

(iii) If AC current density value > 30A/sqm, then ratio between AC current density and DC current density shall be less than 5 over a 24h time period

To monitor ac corrosion risks, coupons shall be installed at the locations where significant ac interference is expected. Coupons shall be used to measure ac current density, dc current density and pipe-to-soil potential measurements.

Mitigation measures shall include reducing the ac voltage/current which can be achieved by connecting pipeline to earthing system (s) through DC decoupling devices so that CP system is not impacted.

Note: The EPC CONTRACTOR, upon receipt of LOI from the COMPANY, shall immediately conduct the computer modelling to assess the effects of AC interference on the pipeline and get the recommendations for mitigation measures. If the CONTRACTOR is not sufficiently experienced to undertake this assessment, CONTRACTOR shall appoint another suitably qualified authority.

This is to avoid delays in the implementation of the mitigation measures which should coincide with pipeline construction.

21.11 Electrical Isolation

Cathodically protected structures shall generally be electrically isolated from other plant, foreign structures / pipelines and electrical and instrument earthing systems.

However it is not always practical to achieve the electrical isolation due to practical reasons. The major hurdle is the presence of highly conductive fluids in the product being transported in the pipelines. The amount and quality of conductive fluid are not constant and vary with time. Whenever conductive fluid volume is more than 5% of the total volumetric flowrate, internal corrosion mitigation measures (isolating spool and external jumper) shall be adopted.

There are various types of products that are transported through pipelines and these can be broadly classified as per Table 9:

Table 9 — Buried Onshore Pipelines - Installation Requirements as per Fluid and Line Type

Product	Line Type	Coating and Laying	Fluid
Oil	Main Oil Line	Coated, buried	Oil, low water content
	Transfer line	Coated, buried	Oil, high water content
	Flowline	Bare, surface laid	Oil, high water content
Water	Transfer line	Coated, buried	Water
	Transfer line	Bare, surface laid	Water
	Transfer line	Coated, surface laid	Water
	Water Injection Flowline / Injection Lines	Bare, surface laid	Water

	Water Injection Flowline / Injection Line	Coated, buried	Water
HC Gas	Producers Flowline	Coated, buried	Gas, condensate, water
	Injection Flowline	Coated, buried	Gas, dry
	Producer Gathering Line	Coated, buried	Gas, condensate, water
	Injection Trunk line / Header	Coated, buried	Gas, dry
Non-HC service	Pipelines	Coated, buried	CO2, N2, dry

The following table shows the pipeline routing and electrical isolation arrangement for various pipelines:

Table 10 ─ Buried Onshore Pipelines - Electrical Isolation Requirements

Pipeline Description	Product	From	Electrical Isolation	To	Electrical Isolation
Oil Flow line	Oil / water	Well	No Isolation	RDS / CDS	Electrical Isolation with jumper
Water flow line	Water	Well	No Isolation	RDS / CDS	No Isolation
Water Injection line (Disposal water)	Water	RDS / CDS	No Isolation	Well	No Isolation
Gas Flow line	Gas / condensate	Well	Electrical Isolation with jumper	GRS / CDS	Electrical Isolation with jumper
Gas Injection line	Dry Gas	RDS / CDS	Electrical Isolation	Well	Electrical Isolation
Oil Transfer Line	Oil / water	RDS	Electrical Isolation with jumper	CDS	Electrical Isolation with jumper

Gas Transfer Line	Gas / condensate	GRS	Electrical Isolation with jumper	CDS	Electrical Isolation with jumper
Dry Gas Transfer Line	Dry Gas	RDS & AGP	Electrical Isolation	CDS	Electrical Isolation
MOL	Oil	CDS	Electrical Isolation	Loading Terminal, Plant	Electrical Isolation
Gas Transfer Line	Dry Gas	CDS	Electrical Isolation	Loading Terminal, Plant	Electrical Isolation
Gas Injection line	Dry Gas	CDS or RDS	Electrical Isolation	Water Wells (WAG)	Electrical Isolation
Gas Injection line	Dry Gas	CDS or RDS	Electrical Isolation	Oil Gas Lift Wells	Electrical Isolation

Monobloc isolating joints (IJs) are the preferred option for the electrical isolation of pipelines.

Isolating flange kits (IF kits) shall be used for flange connections where different materials are used (spec break) in order to avoid galvanic corrosion.

If the pipeline or piping is foreseen to conveying a conductive fluid (more than 5%) an isolating spool shall be used.

Short branch lines, small pipeline facilities and/or crossings of small roads do not always need to be isolated and can sometimes be incorporated in the main pipeline cathodic protection system. If isolation is omitted, the CONTRACTOR shall justify this choice in his basic design.

In pumping stations where the section of PL is AG and it is connected to earthing of equipment, Polarization Cells shall be used to prevent CP current drain to earthing.

Isolating joints / flanges shall never be buried. They shall be installed above ground or in inspection pits.

Parallel pipelines shall be electrically isolated from each other except if running in the same trench and having the same coating system.

Each isolating joint / flange shall be provided with test facilities. The isolating joints or flanges shall be protected using earthing or surge arrestors

If the pipeline isolation is to be designed by others, the CONTRACTOR shall ensure that the arrangement will be adequate to allow effective cathodic protection.

For existing pipelines the CONTRACTOR shall investigate the quality of the existing pipeline isolation and submit with his basic design any requirements for improvements to obtain suitable isolation.

Safety or instrument earthing shall be compatible with the cathodic protection system or shall be isolated using solid state polarization cell(s).

Isolating joints and flanges should be painted in a contrasting colour for easy identification. The paint shall be compatible with the pipeline coating.

Paints containing metallic pigments (such as zinc or aluminium) shall not be used for isolating joints / flanges.

21.12 Anode/Groundbed Installation

21.12.1 ICCP Systems

Deep groundbed ICCP systems shall be used for the permanent protection of buried pipelines.

CONTRACTOR shall include calculations of the groundbed resistance based on the most accurate soil resistivity data available, using established methods and formulae.

The number of anodes shall be calculated based on the design current and current capacity of each anode. The recommended minimum size of the MMO anode is 25mm dia x 1000mm long. The anodes shall be supplied with individual anode cable tail. No splicing shall be allowed in anode cable tail. String anodes shall not be used. The deepest anode shall be numbered as anode number A1 and subsequent anodes shall be numbered as A2, A3.

The anode cable tail shall have a primary insulation of PVDF or ECTFE to avoid the damage by the gases being generated in the deep anodebed. The outer sheath shall be HMWPE. The conductor shall be stranded copper and the minimum size of anode tail cable shall be 1x16 mm^2.

The depth of anodebed shall be decided based on the soil resistivity and water table depth. The separation between two adjacent anodes, end to end, shall not exceed 3m. A column of 3m shall be maintained below the deepest anode. A column of 5m shall be maintained on top of the shallowest anode. The active column shall be 10 m below the static water table.

The minimum number of anodes for a deep anodebed shall be five (5). The minimum active column length shall be 25 m. It may be necessary to install more anodes to limit the groundbed resistance to 0.6 ohms for 20 Amps rating and 0.3 ohm for 20-40 Amps rating where solar power units are used as DC power source.

Backfill current density shall be limited to 1.6 Amps/sqm.

In the detailed design, CONTRACTOR shall specify the method of drilling the deep well, establishing the resistivity of the soil at depth, completion of the borehole and the method of installation of the anodes and backfill.

(a) Cased boreholes

Metal casings may be used at the surface for stabilizing the borehole and in the active section of the groundbed. Casings at depth shall be electrically isolated from metal casings and structures at the surface.

To achieve such isolation, plastic casings can be used. Alternatively a well coated metallic casing pipe can be used for the non-active column of the anodebed.

(b) Uncased boreholes

Uncased boreholes may be used if the anodebed can be installed immediately after the drilling and the borehole does not collapse. All groundbed materials, anodes with cable, vent pipe and coke breeze, shall be available at site prior to commencement of the drilling.

It shall be ensured that all anodes shall exhibit uniform resistance. Remedial actions shall be taken by contractor if resistance of any particular anode exceeds 20% of average anode resistance.

Deep groundbeds shall be provided with adequate venting pipes to prevent gas blocking of the well. Vent pipe material shall be chlorine resistant. The vent pipe shall have fine slits / perforation. The size of perforation should be small so that coke backfill does not flow into the vent pipe.

Positioning of the groundbed, there should not be any buried metallic structure at the groundbed location and between the groundbed and the pipeline being protected. The groundbed shall be placed so as to maintain the following minimum separation:

1. Groundbed to the structure being protected

Minimum separation is 100 m.

2. Groundbed to any foreign buried structures:

Preferred minimum separation is 100 m. However due to space limitation, it may not be feasible to maintain 100 m separation in all the cases. In such case, the distance of the foreign structure and groundbed depends upon the resistivity of soil where groundbed is installed and current output of groundbed. The following guidelines shall be followed:

Table 11 — Buried Onshore Pipelines - Groundbed Current Output

Minimum distance of structure to	Groundbed Current Output (Amps)			
	0-20	21-40	41-60	61-80
Deep Groundbed (m)	35	65	95	125
Surface Groundbed (m)	65	125	190	250

Notes.

(i) The calculations are based on 500 ohm.cm soil resistivity for deep groundbed and 1,000 ohm.cm for Surface Groundbed.

(ii) Surface groundbed separation is applicable for existing groundbeds.

(iii) In case of higher resistivity, the distance shall be increased proportionately. It shall be reviewed and approved by COMPANY.

3. Groundbed and existing anode groundbeds (excluding close anode systems) :

Preferred distance is 100 m. However if it is not feasible, minimum separation of 50 m shall be used. Crowding factor of 1.1 m shall be used to calculate resistance of each groundbed and corresponding voltage of DC power source. Crowding factor of 1.05 shall be used for 100 m spacing.

Where groups of structures exist, shielding may occur. In such instances, it is sometimes desirable to distribute groundbeds such that the minimum separation is less than that given above. COMPANY shall be consulted in such case and approval shall be obtained before construction.

In any event the cable connecting the CP power supply and its associated groundbed(s) should be minimized and shall not exceed 500 m.

4. Distance from High Voltage Overhead Transmission Lines

It shall be ensured that the groundbed is not constructed immediately below any overhead transmission line. The minimum lateral separation shall be:

Table 12 — Buried Onshore Pipelines - Minimum Separation Between Groundbed and Overhead Lines

OHL rating (KV)	33	>33
Min. separation between groundbed and OHL (m)	100	150

21.12.2 SACP Systems

Temporary CP in the form of sacrificial anodes are generally applied to structures with a permanent ICCP system which is not operational until construction works have been completed and ac power fully available for operation of the ICCP system.

This would primarily apply to buried pipelines i.e. flowlines, inter station pipelines and transmission lines.

Temporary CP for buried pipelines shall take the form of pre-packaged zinc or magnesium alloy anodes. The anode weight shall be calculated based on design current, design life (nom. 2 years, see sec.21.3), anode alloy capacity, efficiency and utilization factor. The anode tail cable shall be 1x10 mm^2 Cu/XLPE/PVC red cable.

Anodes shall be installed horizontally / vertically and laid alongside the buried pipeline/piping, at / below invert depth and with a 1-2m separation.

Anode cable tails shall be terminated within an aboveground test facility enabling monitoring of the anode performance and structure potentials during the temporary CP. During commissioning of the permanent CP system the temporary anode cable tail shall be disconnected and the end of the cable wrapped with electrical tape, to prevent accidental connection to the test facility terminals. The anode cable tail shall be left secured within the test facility.

21.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to earth tests of new groundbed anodes and zinc earthing electrodes, calibration checks of permanent reference electrodes, testing of isolation joints and insulated flanges, coating inspection survey, using D.C voltage gradient technique (i.e. DCVG).

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for the testing of pipeline isolation

(b) Procedures for natural potential surveys

(c) Procedures for energizing cathodic protection hardware

(d) Procedure for testing and adjustment of pipeline-to-soil potential

(e) Requirements for polarization of the pipeline

(f) Procedures for full ON / OFF potential surveys

(g) Procedures for interference testing

(h) Close Interval Potential Survey (CIPS)

(i) Procedure for mitigation measures if interference is detected during the commissioning (if the positive swing on the foreign structure exceeds 20 mV)

(j) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the pipeline

(k) Required format of the commissioning report

(l) Procedure for clearing the Punch List items

21.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the pipeline, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 13.

Table 13 — Buried Onshore Pipelines - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, measurement of the earthing system, control of instruments, and measuring of the output voltage and current	One to three years
Unidirectional drainage stations	Visual check of the unidirectional drainage unit and reading of the integral cathodic protection instrumentation	One month
Unidirectional drainage stations	Comprehensive functional tests of the unidirectional drainage station e.g. control of the PRE, functionality of the diodes and their protection devices, setting of resistors, control of instruments, and measurement of the drain point potential and current	One to three years
Connections to foreign structure (resistive or direct bond)	Measurement of current flow	One year

Connections to foreign structure (resistive or direct bond)	Comprehensive functional tests of the device and measurement of the current flow (magnitude and direction) and the potential	One to three years
Grounding systems connected to the pipeline and related to the CP system or corrosion mitigation system	Comprehensive functional tests of the devices and determination of the groundbed resistance and the current flow through the mitigation system (if any)	One to three years
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years[(ii)]
Selected test stations	Measurement of 'CP ON' potential	One year
All test stations	Measurement of 'CP OFF' / polarised potential [(i)]	Three years
Galvanic anode station	Visual check of the stations and measure the pipe-to-soil potential	One year
Galvanic anode station	Comprehensive functional tests of the galvanic station e.g. resistor setting, efficiency of the bonding connection and measurement of the pipe-to-soil potential	Three years

Notes.

(i) Where stray current can influence the 'CP OFF' potential measurements, alternative measurement techniques may be considered if demonstrated to be accurate and effective

(ii) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years

22 TECHNICAL REQUIREMENTS – BURIED IN-PLANT PIPING NETWORK

22.1 General

The CP design for buried in-plant piping networks shall be based on a permanent impressed current system designed in general accordance with the requirements of ISO 15589-1.

For short isolated sections of buried in-plant piping, permanent protection by a sacrificial anode system maybe applied, e.g. fire hydrant buried metallic piping (where connected to a non-metallic firewater main). This to be reviewed and approved by the COMPANY.

Temporary protection of buried in-plant piping networks shall also be provided, based on a sacrificial anode system

The section buried in-plant piping network, covers design criteria, parameters and calculations of cathodic protection systems used for buried metallic piping located within the boundaries of a plant or station, e.g. buried piping associated with oil / gas / water / drainage and fire hydrant piping.

22.2 CP Criteria

The buried in-plant piping-to-soil potential is the criterion for evaluating effectiveness of cathodic protection.

Impressed current CP systems shall be designed such that instantaneous "OFF" / Polarised potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the buried in-plant piping network, over its design life, to achieve an Instant "OFF" / Polarised potential over the entire buried piping, equal to or more negative than stated in Table 14 below. To avoid detrimental effects on the applied coating (disbondment) or on the structure (hydrogen induced stress cracking) due to over protection, Instant "OFF" / Polarised potentials for carbon steel shall not be more negative than the overprotection limit value as stated in Table 14 below.

Some corrosion resistant steels and high strength steels (e.g. Duplex stainless steels) are more susceptible to hydrogen induced stress cracking than carbon steel. The protection criteria for structures made of such materials shall be determined on a case by case basis. This is also applicable when designing a cathodic protection system for buried in-plant piping network when crossing or approaching other buried in-plant piping made of such a material.

The protection potential values stated for aerobic environments shall also apply to anaerobic environments where soil investigation has confirmed the presence of active sulphate reducing bacteria.

In addition, these protection potential values shall also apply to high temperature effects where operating temperatures greater than 60°C are encountered.

Table 14 — Buried In-Plant Piping - Protection Criteria for ICCP Systems

ENVIRONMENT	Instantaneous "OFF" / Polarised Potentials, mV w.r.t		
	$Cu/CuSO_4$	Ag/AgCl	$Zn/ZnSO_4$
Protection potential for steel in aerobic/anaerobic soil environment.	-950	-900	+150
Over protection limit for carbon steel in soil / water environment	-1200	-1150	- 100
Over protection limit for Duplex Stainless Steel (DSS) / SS	-1100	-1050	0

Notes.

(i) Cu/CuSO4 reference cell is used for buried in-plant piping in normal soil where chloride content is low

(ii) Ag/AgCl reference cell is used in soils having high chloride content (more than 1000 ppm)

(iii) Zn/ZnSO4 reference cell is used in soils applications for special monitoring purposes only

(iv) 100 mV polarization criteria may be considered (subject to acceptance by COMPANY) in special cases if it is not possible to achieve the potentials listed in Table 14

(v) 'NATIVE' potentials, for pipelines not under the influence of a cathodic protection system and/or stray interference effects, shall be considered as approx. -500mVcse

(vi) 'AS-FOUND' potentials shall be applied to pipelines already indicating potentials of -950mVcse or more negative as a result of interference / influence from other (existing) cathodic protection systems, prior to commissioning of the pipeline dedicated CP system. In such events, COMPANY shall be advised and further investigation shall be required to determine the cause of the excessive negative potentials

(vii) For sacrificial CP system ON potential values as per Table 14 above shall be considered.

(viii) For sacrificial CP system where 'AS-FOUND' potential of flowline is already -950 mVcse or more negative due to interference or influence of other CP systems, protection criteria from the installed CP system shall result in a net flow of current to the pipeline and a negative polarization observed-

22.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for buried in-plant piping network CP systems, based on the different CP systems applied, shall be as follows:

- Permanent ICCP system — 30 years,

- Permanent SACP system – 20 years,
- Temporary SACP system – 2 years

Note.

(i) If the normal life of components of the cathodic protection system is shorter than the design life of the equipment or if adequate control of the cathodic protection levels at the beginning and at the end of the design life are technically incompatible, the CONTRACTOR shall include, and justify in CP design, the installation of a system based on this shorter life and shall include methods and instructions for future upgrading of the system.

This may be the case with sacrificial anode systems.

(ii) Sacrificial CP system based on magnesium anodes, generally have an operating life expectancy of upto 10years. Where magnesium anodes are used for permanent SACP systems, measures shall be incorporated for anode replacement after 10 years to ensure the required 20 year design life is achieved.

22.4 Anode/Groundbed Parameters

22.4.1 Anodes

Anodes for use in the protection of buried in-plant piping network shall be as follows:

- Mixed metal oxide (MMO) coated titanium tubes or wire (ICCP)
- Magnesium alloy anodes (SACP)
- Zinc alloy anodes (SACP)

The MMO/titanium anode shall have the following design parameters:

Table 15 – Buried In-Plant Piping - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Tubular Anode	Design Values
Tubular anode size (min)	25mm dia. X 1000mm long
Galvanised Steel canister	150mm dia. X 1500mm long
Titanium (tubular)	ASTM B338, grade 1
Current density (in carbonaceous backfill)	Max. 50 A/m^2
Current density (in calcined petroleum)	Max. 100 A/m^2
MMO/Titanium parameters - Wire Anode	**Design Values**
Wire anode size (min)	3.0mm diameter

Geotextile sock	38mm diameter
Titanium (wire)	ASTM B863, grade 1
Current density (in soil)	Max. 50 A/m^2
Current density (in calcined petroleum)	Max. 100 A/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly.

The magnesium alloy anode shall have the following design parameters:

Table 16 — Buried In-Plant Piping - Magnesium Alloy Anode Design Parameters

Magnesium alloy parameters	Design Values	
	Std potential	Hi-potential
Anode solution potential	-1500 to -1550mVcse	-1750 to -1770mVcse
Electrochemical capacity	1100 A-hr/kg	1100 A-hr/kg
Anode density	1.94g/cm^3	1.94g/cm^3
Efficiency	50%	50%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Appendix 1 for details)

(iii) Efficiency values based on an anode current density of approx. 320mA/m^2

(iv) Details of anode chemical composition given in Appendix 1

(v) Magnesium anodes should not be used if the resistivity of the electrolyte is higher than 15,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met

The zinc alloy anode (ASTM B418 Type II) shall have the following design parameters:

Table 17 — Buried In-Plant Piping - Zinc Alloy Anode Design Parameters

Zinc alloy parameters	Design Values
Anode solution potential	-1100mVcse
Electrochemical capacity	738 A-hr/kg
Anode density	7.00g/cm^3
Efficiency	90%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Appendix 1 for details)

(iii) Details of anode chemical composition given in Appendix 1

(iv) Zinc anodes should not be used if the resistivity of the electrolyte is higher than 1,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met.

22.4.2 Groundbeds

Distributed or piggy backed anodes or combination of both is preferred for the protection of buried in-plant piping network to avoid current drain to the other structures.

If feasible, all buried in-plant piping shall be bonded to form a single cathode. However current demand in such cases shall be higher considering current drain to other structures and earthing.

CONTRACTOR shall evaluate both the systems and propose more viable system to COMPANY for review and approval.

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system
- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- Its location is a distributed close anode to the buried in-plant piping, to provide a regular distribution of current along the buried in-plant piping
- The risk of causing harmful interference on other buried structures is minimized
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

The selection of the location and the type of groundbed shall depend on local conditions such as:

- Soil conditions and resistivity at various depths
- Available terrain (within the plant and in close proximity to the buried in-plant piping)
- Risk of shielding (specially for parallel in-plant piping and concrete footings)
- Risk of damage by excavation (if groundbed installed at same time as on-going in-plant construction)

Sacrificial CP systems shall be used for the permanent protection of short isolated sections of buried in-plant piping and for the temporary protection of buried in-plant piping with a permanent ICCP system during the construction stage and until the ICCP system is energized.

The design of a sacrificial anode cathodic protection system shall be based on the anode current and weight meeting the design requirements.

The design current shall be calculated based on the surface area, design current density at the operating temperature and current allowance. Anode weight shall be calculated based on design current, design life, anode alloy capacity, and efficiency and utilization factor.

The anode tail cable shall be a 1x10 mm^2 Cu/XLPE/PVC red cable (where applicable).

The anode current output shall be calculated based on driving voltage and total circuit resistance. Current output shall be more than the design current. It may be necessary to increase the number of anodes to meet the design current output.

22.5 Design Resistivity

Design resistivity values shall be based on the soil resistivity measurements recorded during pre-design site surveys.

22.6 Design Current Density

The ICCP design for buried in-plant piping network shall be based on a 'close anode' system, the CONTRACTOR shall carry out voltage gradient calculations to determine the spacing between the anodes required to achieve protection of the pipework during its design life.

The current densities in Table 18 shall be used as minimum design values for new construction projects and are to be related to the total pipeline surface area and take into account coating deterioration during the design life of the pipeline.

Table 18 — Buried In-Plant Piping - Design Current Densities for Permanent ICCP Systems

Type of coating	Current density for 'initial' design mA/m^2	Current density for 'final' design mA/m^2
3LPE or 3LPP	0.001	0.05
FBE	0.02	0.4

Liquid epoxy Coal tar or bituminous coating	0.2	0.8

Notes.

(i) Values derived from ISO 15589-1:2015 Table 3.

(ii) Initial current density values are based on the minimum 'optimized' design values and are applicable for the design of sacrificial anodes for temporary CP systems.

(iii) Final current density values are based on the minimum 'conservative' design values and are applicable to the design of impressed current systems for long term operation.

(iv) The values given in Table 18 account for the buried in-plant piping operating at not more than 30°C temperatures. Where pipeline operating temperatures exceed 30°C a temperature correction factor shall be applied: current density value shall be increased by 25% for each 10°C rise in operating temperature above 30°C.

The CP design for short isolated sections of buried in-plant piping, e.g. fire hydrant piping, shall be based on a permanent sacrificial anode CP system.

The CONTRACTOR shall carry out the SACP system calculations to determine the quantities of anodes to meet the mean and final design currents and the weight/mass requirements.

The current density values take into account coating deterioration during the design life of the buried in-plant piping.

The current density values to be applied in the CP design shall be as detailed in Table 19.

Table 19 — Buried In-Plant Piping - Design Current Densities for Permanent SACP Systems

Type of coating	Current density for 'final' design mA/m^2
3LPE or 3LPP	0.02
FBE	0.2
Liquid epoxy, Coal tar or bituminous coating	0.3

Notes.

(i) Values derived from ISO 15589-1:2015 Table 3.

(ii) Final current density values are based on the maximum 'optimized' design values and are applicable for the design of sacrificial anodes for permanent CP systems.

(iii) The values given in Table 19 account for the buried in-plant piping operating at not more than 30°C temperatures. Where pipeline operating temperatures exceed 30°C a temperature correction factor shall be applied: current density value shall be increased by 25% for each 10°C rise in operating temperature above 30°C.

(iv) A 50% additional current allowance shall be considered in the design of the SACP system to allow for probable current drain to adjacent structures.

Current density values for additional bare structures to be accounted for in the in-plant buried piping network CP design shall be as detailed in Table 20.

Table 20 — Buried In-Plant Piping - Current Densities for Bare (non-coated) Structures

Structure	Current Density (mA/m²)
Bare steel in sand/soil	20
Copper ground rods	50
Bare tinned copper cable	70

22.7 Coating Breakdown Factor

Current density values detailed in Table 18 and Table 19 include for coating deterioration during the design life of the buried in-plant piping network. Application of additional coating breakdown factors are therefore not required.

22.8 Surface Area

Surface area of the buried in-plant piping to be afforded cathodic protection shall be based on the total buried in-plant piping network surface area.

22.9 Monitoring Facilities

22.9.1 Cable Connection to Piping

The cable connection to the in-plant buried piping shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the piping.

Cable connections shall not be carried out on bends or within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All below grade cable connections shall be fully encapsulated to comply with the original coating standards. A holiday test shall be conducted before backfilling.

The following methods shall be used for cable connections:

Table 21 — Buried In-Plant Piping - - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Existing Piping	Welded Pad Note i	Pin Brazing Note ii
New Piping	Welded Pad	Welded Pad Note ii

Notes.

(i) A welded pad is preferred for current carrying cables. In case it is not possible to use a welded pad connection to the existing piping, pin brazing connection may be allowed. The connection shall be done by an experienced and approved welder / operator.

(ii) The cable shall be looped around the piping to avoid damage to the connections by accidental pulling of the cable.

22.9.2 Monitoring Facility Types

For buried in-plant piping network protected by a permanent close anode ICCP systems, monitoring facilities shall consider the buried length of in-plant piping and the anode type / number installed. As a minimum, potential monitoring facilities shall be installed at each end of the buried in-plant piping sections. For longer buried in-plant piping sections the maximum spacing between test facilities shall be 50m.

For ICCP systems using discrete anodes (e.g. MMO) distributed along the buried in-plant piping, monitoring facilities shall be located at the most remote points from the anode(s).

Each structure shall have a discrete drain point connection and a separate negative return cable.

Where groups of structures are to be protected using the same current source, cables shall run from each structure to common, centrally located NDB(s). Cables from these shall run to an NJB and cables from this shall terminate at the current source

Test facilities shall be either above ground conduits with a terminal head/box on top or a test facility flush with the ground surface and cable termination in a below ground terminal head/box.

The choice of test facility shall depend upon the location within the plant and its potential impact on equipment/services within the plant.

One test facility shall be provided per fire hydrant piping for monitoring the CP system. The test facility shall be located at a safe place (according to site conditions). The test facility shall contain a variable control resistor to control the anode current (to enhance anode life) and facilitate installation of new anodes in the future without touching the hydrant.

In paved areas a monitoring pit shall be provided over the buried in-plant piping near the test post. It shall comprise of a 2" UPVC tube with a removable end cap. The tube length shall depend upon the depth of the buried in-plant piping. Bottom of the tube shall be 150mm above the top of the buried piping and flush with grade level. If it is permitted to extend the tube above grade level, then a 300mm length shall be considered above grade.

The CONTRACTOR shall propose within their design the test facility types to be used based on their site investigations and review of construction layout plans. This to be reviewed and approved by the COMPANY.

22.10 Interference

22.10.1 DC Interference

CP systems of adjacent structures can interfere with the protected structure.

DC interference can lead to accelerated corrosion of affected structure.

The CONTRACTOR shall investigate possible sources of detrimental DC stray currents and include proposals in the design on how to mitigate the effect of such stray currents on the protected structure.

CONTRACTOR shall carry out a stray current survey at the time of commissioning.

For interaction effects on secondary structures as a result of the CP system on the protected structure, the following shall be applied:

(a) On secondary structures without a CP system, maximum positive potential change on any part of the secondary structure, resulting from interaction, should not exceed 20 mV. In case a positive swing of more than 20 mV, mitigation measures shall be adopted by the CONTRACTOR

(b) On secondary structures with a CP system, unacceptable interference shall be deemed when the 'Polarized' potential on the secondary structure does not achieve the protection potential range as per Table 14.

Mitigation measures include:

(a) Prevention of pickup of stray current by improved isolation or shielding

(b) Re-distribution of CP current sources, adjustment of current output from mutually interfering CP power sources

(c) Installation of metallic bonds between affected structures

(d) Application of unidirectional control devices such as diodes or reverse current switches

(e) Use of galvanic anodes on the anodic section

22.10.2 AC Interference

AC interference is not considered an issue for buried in-plant piping networks.

22.11 Electrical Isolation

Buried in-plant piping network shall be cathodically protected using an impressed current close anode system (distributed or linear anode system), designed to ensure that current flows preferentially to the buried in-plant piping whilst achieving an even spread of protection. It is not, therefore, required to provide any isolation of this piping from tanks, vessels or plant earthing systems.

However, for short isolated sections of buried in-plant piping protected by a permanent sacrificial anode CP system, electrical isolation in the form of monobloc isolating joints (IJs) or isolating flange kits (IF kits), shall be considered. Where such situations occur CONTRACTOR shall advise COMPANY.

22.12 Anode Installation Procedure

22.12.1 ICCP Systems

Distributed anodes, linear anodes or piggy backed anodes shall be used in the plants for the protection of the buried in-plant piping network. This helps in avoiding the current drain to foreign structures.

The depth of the distributed anodes shall be based on the soil resistivity, and spacing shall be governed by the voltage gradient.

The number or length of anodes required shall be calculated based on design current and current capacity of each anode.

Anodes shall be MMO tubular anodes encased in a galvanised steel (GS) canister filled with calcined coke backfill or MMO wire anodes piggybacked on to a power cable and encased in a geotextile sock filled with calcined coke.

Note. ADNOC have experienced a number of historical failures of piggy back wire anodes. To ensure the integrity and design life of the wire anode system, anode-to-cable connections shall be undertaken by the piggy back wire anode fabricator/manufacturer. All connections shall be tested in accordance with a Company approved ITP specifying He leak tests and resistance tests.

The recommended minimum sizing for anodes shall be:

(i) MMO tubular: 25mm diameter x 1000mm length,

(ii) GS canister: 150mm diameter x 1500mm length,

(iii) MMO wire: 3.0mm diameter

(iv) Geotextile sock : 38mm diameter

The anode cable tail shall have a primary insulation of PVDF or ECTFE to avoid the damage by the gases being generated from the anodes. The outer sheath shall be HMWPE. The conductor shall be stranded copper and the minimum size of anode tail cable shall be 1x16 mm^2.

22.12.2 SACP Systems

Sacrificial anode CP systems are generally applied as: temporary CP to structures with a permanent ICCP system which is not operational until construction works have been completed and ac power fully available for operation of the ICCP system, or as permanent CP system for short isolated buried in-plant piping, e.g. fire hydrant piping.

Sacrificial anode CP for buried in-plant piping network shall take the form of pre-packaged zinc or magnesium alloy anodes. The anode weight shall be calculated based on design current, design life (see sec.22.3), anode alloy capacity, efficiency and utilization factor. The anode tail cable shall be 1x10 mm^2 Cu/XLPE/PVC red cable.

Anodes shall be installed horizontally / vertically and laid alongside the buried in-plant piping, at / below invert depth and with a 1-2m separation.

Anode cable tails shall be terminated within an aboveground test facility enabling monitoring of the anode performance and structure potentials during the operation of the temporary or permanent CP system.

The test post shall be provided with a resistor and shunt to control and monitor anode current output.

A watering arrangement shall be provided to periodically water the anode (s).

For temporary CP systems, during commissioning of the permanent CP system, the temporary anode cable tail shall be disconnected and the end of the cable wrapped with electrical tape, to prevent accidental connection to the test facility terminals. The anode cable tail shall be left secured within the test facility.

22.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to earth tests of new groundbed anodes, calibration checks of permanent reference electrodes.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for energizing cathodic protection hardware

(c) Procedure for testing and adjustment of buried in-plant piping-to-soil potential

(d) Requirements for polarization of the buried in-plant piping

(e) Procedures for full ON / OFF potential surveys

(f) Procedures for interference testing

(g) Procedure for mitigation measures if interference is detected during the commissioning (if the positive swing on the foreign structure exceeds 20 mV)

(h) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the buried in-plant piping network

(i) Required format of the commissioning report

(j) Procedure for clearing the Punch List items

22.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the buried in-plant piping network, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 22.

Table 22 — Buried In-Plant Piping - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, measurement of the earthing system, control of instruments, and measuring of the output voltage and current	One to three years

Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years[(ii)]
Selected test stations	Measurement of 'CP ON' potential	One year
All test stations	Measurement of 'CP OFF' / polarised potential [(i)]	Three years
Galvanic anode station	Visual check of the stations and measure the buried in-plant piping-to-soil potential	One year
Galvanic anode station	Comprehensive functional tests of the galvanic station e.g. resistor setting, efficiency of the bonding connection and measurement of the buried in-plant piping-to-soil potential	Three years

Notes.

(i) Where stray current can influence the 'CP OFF' potential measurements, alternative measurement techniques may be considered if demonstrated to be accurate and effective

(ii) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years

23 TECHNICAL REQUIREMENTS — AST EXTERNAL BOTTOM

23.1 General

The CP design for the external bottom plates of above ground storage tanks, shall be based on a permanent impressed current system.

The CP system shall be installed below the AST in the sand infill within the concrete ringbeam supporting the tank.

Tanks supported on a concrete pad for the full diameter of the tank, shall not be considered for cathodic protection due to the shielding effects of the concrete impeding the CP DC current flow to the tank bottom.

The section AST external bottom, covers design criteria, parameters and calculations of cathodic protection systems used for the external protection of above ground storage tanks installed on concrete ringbeams with a sand infill which supports the tank bottom.

23.2 CP Criteria

The external bottom AST-to-soil potential is the criterion for evaluating effectiveness of cathodic protection.

Impressed current CP systems shall be designed such that instantaneous "OFF" / Polarised potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the AST external bottom, over its design life, to achieve an Instant "OFF" / Polarised potential over the entire AST external bottom surface, equal to or more negative than stated in Table 23 below. To avoid detrimental effects on the applied coating (disbondment) or on the structure (hydrogen induced stress cracking) due to over protection, Instant "OFF" / Polarised potentials for carbon steel shall not be more negative than the overprotection limit value as stated in Table 23 below.

The protection potential values stated for aerobic environments shall also apply to anaerobic environments where soil investigation has confirmed the presence of active sulphate reducing bacteria.

Table 23 — AST External Bottom - Protection Criteria for ICCP Systems

ENVIRONMENT	Instantaneous "OFF" / Polarised Potentials, mV w.r.t	
	$Cu/CuSO_4$	$Zn/ZnSO_4$
Protection potential for steel in aerobic/anaerobic soil/sand environment.	-950	+150
Over protection limit for carbon steel in soil/sand environment	-1200	- 100

Notes.

(i) Cu/CuSO4 reference cell is used in normal soil where chloride content is low

(ii) Zn/ZnSO4 reference cell is used in soils applications where chloride content is low and long life operation/usage is required. These are considered the preferred option for under tank monitoring.

(iii) 100 mV polarization criteria may be considered (subject to acceptance by COMPANY) in special cases if it is not possible to achieve the potentials listed in Table 23

23.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for AST external bottom CP systems, shall be as follows:

- Permanent ICCP system – 30 years,

23.4 Anode/Groundbed Parameters

23.4.1 Anodes

Anodes for use in the protection of AST external bottom surfaces shall be as follows:

- Mixed metal oxide (MMO) coated titanium ribbon or wire (ICCP)

The MMO/titanium anode shall have the following design parameters:

Table 24 – AST External Bottom - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Ribbon Anode	**Design Values**
Ribbon anode size (min)	6.35mm wide X 0.6mm thick
Titanium conductor bar size (min)	12.57mm wide X 1mm thick
Titanium (ribbon, conductor bar)	ASTM B265, grade 1
Current density (in sand/soil) (i)	Max. 3 A/m^2
MMO/Titanium parameters - Wire Anode	**Design Values**
Wire anode size (min)	3.0mm diameter
Titanium (wire)	ASTM B863, grade 1
Current density (in soil) (ii)	Max. 50 A/m^2

Notes.

(i) MMO/Ti ribbon anode current density values based on standard manufacturers values for a lifetime of 50 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly.

(ii) MMO/Ti wire anode current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly

23.4.2 Groundbeds

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system
- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- Its location is a close anode to the AST external bottom, to provide a uniform distribution of current to the entire exposed surface of the AST external bottom
- The risk of causing harmful interference on other buried structures is minimized
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

Anode groundbeds for AST external bottom protection shall be installed within the sand infill in the concrete ringbeam tank support structure. The type of groundbed layout shall depend on the type of anode material used as:

- MMO/Ti ribbon anodes - grid anode arrangement
- MMO/Ti wire ‘piggyback’ anodes - concentric loops

Note. ADNOC have experienced a number of historical failures of piggy back wire anodes. To ensure the integrity and design life of the wire anode system, anode-to-cable connections shall be undertaken by the piggy back wire anode fabricator/manufacturer. All connections shall be tested in accordance with a Company approved ITP specifying He leak tests and resistance tests.

23.5 Design Resistivity

The sand infill below the AST shall be mechanically washed sand conforming to ASTM C778 type “20-30 sand” with the following properties:

- Maximum Chlorides (Cl-) 300ppm
- Maximum Sulphates (SO42-) 200ppm
- pH between 6.5 and 8.5

Resistivity values for the sand infill shall be measured, by soil box, from a sample taken of the infill to be used. This shall be used in the design calculations. Where this is not feasible at the start of design, then the following assumptions shall be used for resistivity values and applied in the design calculations:

- Maximum sand resistivity : 50,000 ohm.cm
- Minimum sand resistivity : 15,000 ohm.cm

The CP system shall be designed to be able to operate in both resistivity conditions stated above.

23.6 Design Current Density

The CP design for ASTs and vessels shall be dependent on the surfaces to be protected, whether 'external' or 'internal'.

The 'external' surfaces of ASTs shall be the bottom of the tank in contact with the sand pad support. Design of the CP system shall be based on a 'close grid anode' system installed below the tank bottom in the sand pad support.

The CONTRACTOR shall carry out voltage gradient and attenuation calculations to determine the depth of the anode grid below the tank bottom, and the spacing of the MMO anode ribbons and the TI conductor bars.

The current densities and coating breakdown factors to be applied in the CP design shall be as detailed in Table 25.

Table 25 – AST External Bottom - Current Densities and Coating Breakdown Factors

Sand/Soil Resistivity ($ohm.cm^2$)	Current density for bare steel (mA/m^2)	Coating breakdown factor for 'final' design
≥10,000	10	50%
Between 5,000 to 10,000	20	50%

Notes.

(i) Coating breakdown factor accounts for the initial coating free zone around the plate edges (welding zone) and the deterioration of the coating at the end of design life.

(ii) Current densities are based on 30°C operating temperature, above 30°C current density values shall be increased by 25% per 10°C rise in temperature.

23.7 Coating Breakdown Factor

Coating breakdown factors for AST external bottoms are detailed in Table 25. Application of additional coating breakdown factors are not required.

23.8 Surface Area

Surface area of the AST external bottom to be afforded cathodic protection shall be based on the total exposed tank external bottom surface area in contact with the sand infill within the concrete ringbeam support.

23.9 Monitoring Facilities

23.9.1 Cable Connection to Tank

The cable connection to the tank shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the structure.

Cable connections shall not be carried out within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All cable connections shall be fully encapsulated to comply with the original coating standards.

The following methods shall be used for cable connections:

Table 26 – AST External Bottom - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Tank	Welded Pad	Welded Pad

23.9.2 Monitoring Facility Types

Monitoring of the CP system applied to the external 'bottom' of the AST shall be based on the following:

(a) Permanent zinc/zinc sulfate reference electrodes; six (6) no. installed with one (1) no. at the tank centre and the remaining five (5) no. at 1.5m from the concrete ring wall evenly distributed along the perimeter of the tank,

(b) Three (3) no. non-conductive perforated tubes wrapped in geotextile cloth installed perpendicular to the close anode distribution to allow survey with a portable reference electrode. The monitoring tubes shall be laid across at 1/3, 1/2, and 2/3 of the tank diameter and shall be opened at both ends and attain the full diameter of the tank at the designated locations. Caps shall be provided for the ends of each tube and a polypropylene rope laid with the full length of each monitoring tube to assist in drawing a portable reference electrode through the tubes.

(c) Three (3) no. corrosion coupons shall be installed at 100mm depth from the tank bottom with the reference electrodes; one (1) no. at tank centre, and two (2) no. close to the concrete ring wall,

(d) Two (2) electrical resistance corrosion probes shall be installed; one (1) no. close to the centre of the tank and one (1) no. at 1500mm from the concrete ring wall,

All cable tails to monitoring equipment shall be routed out from under the tank through a conduit in the concrete ringbeam, located close to the conduit for anode feeder cables.

A monitoring test box shall be located adjacent to the tank and the cable conduit, for termination of all monitoring equipment cables.

A further junction box shall be welded to the side of the tank, close to the monitoring test box, and shall contain a terminal point for the main negative drainpoint cable and one for the tank negative monitoring cable. The negative monitoring cable shall be routed from the welded junction box to the monitoring test box.

23.10 Interference

23.10.1 DC Interference

For new constructions, the AST external bottoms and the associated CP system installed beneath it are enclosed within a HDPE liner/barrier applied to the internal walls and bottom of the concrete ringbeam support.

The HDPE liner will alleviate the possible dc interference effects from the tank bottom CP system on the steel reinforcement within the concrete ringbeam and will protect the tank bottom from external dc interference effects.

23.10.2 AC Interference

AC interference is not considered an issue for AST external bottoms..

23.11 Electrical Isolation

Electrical isolation is not required for the pipework coming off the ASTs as the cathodic protection systems applied: grid anode / piggy backed anode for the external bottom surfaces, are based on a close anode CP system which will ensure current flow preferentially to the tank bottom surface.

Use of a barrier/lining under the tank bottom, surrounding the tank support backfill and CP anode system, will also assist in alleviating the problems associated with current drain to the station earthing.

23.12 Anode Installation Procedure

Protection of external tank bottom plates is mandatory for all steel tanks in contact with soil.

The CP system shall be based on either MMO/Ti ribbon anodes laid in a grid pattern or MMO/Ti ‘piggyback’ wire anodes laid in concentric loops, installed in the tank support sand base or sand infill in the concrete ringbeam.

Secondary containment barriers, HDPE liners, shall be installed beneath the tank or within the concrete ring beam. The CP system shall be installed in between the tank bottom and the liner, to ensure it is not shielded from the tank bottom.

The MMO/Ti ribbon anodes shall be laid in a parallel arrangement with ribbon to ribbon spacing calculated based on the formula:

Anode spacing (maximum) = 2.d.tan 60

Where d = depth of anode installation (metres).

Piggyback wire anode loops shall also be laid with a loop-to-loop spacing calculated as per the above formula.

The anode spacing however shall be limited to maximum 1 meter and should be evenly distributed in the entire surface of the tank bottom. The maximum anode to tank edge periphery distance shall not be more than half of the anode spacing.

Anode depth shall nominally be 350 - 400mm below tank base plates, with the HDPE liner a further 100-150mm below the anodes.

For grid anode layouts, titanium conductor bars shall be laid perpendicular across the MMO/Ti ribbon anode with a maximum spacing of 6m between each conductor bar. One (1) Ti conductor bar shall be laid, at the centre of the tank, parallel to the ribbon anodes. Additional conductor bars shall be provided near the tank edge in case the gap between conductor bar and tank edge is more than 3m.

For tank diameters less than 15m, conductor bar spacing shall be reduced to 3 or 4m.

At each crossing point between ribbon-conductor and conductor-conductor, spot welding shall be undertaken to bond the items together.

Each conductor bar shall be provided with an independent power feed. In case the single length of a conductor bar exceeds 35m, two (2) power feeds shall be provided for the conductor bar, at opposite ends.

Power feeds shall be arranged to ensure uniform current distribution covering the entire tank bottom.

Power cables for the grid anode power feeds and 'piggyback' wire anode shall have a primary insulation of XLPE and an outer sheath shall be HMWPE. The cable conductor shall be stranded copper and the minimum size of cable shall be 1x16 mm^2.

Note: XLPE / PVC cables are considered adequate in chloride free sand.

Prior to construction/installation of the undertank CP system, resistivity measurements of the sand infill shall be taken and confirmed against the assumed design values. Any measured values outside of this range shall be brought to the attention of the COMPANY for evaluation of possible impact on CP design.

23.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to tank structure tests of the anode system (to ensure no electrical shorting between anode and tank structure), calibration checks of permanent reference electrodes.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for energizing cathodic protection hardware

(c) Procedure for testing and adjustment of the AST external bottom-to-soil/sand potential

(d) Requirements for polarization of the AST external bottom

(e) Procedures for full ON / OFF potential surveys

(f) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the AST

(g) Required format of the commissioning report

(h) Procedure for clearing the Punch List items

Note.

During construction, the tank bottom floor may not sit fully supported and in contact with the sand infill in the concrete ringbeam.

Pre-commissioning and commissioning of the undertank ICCP system shall only be undertaken when the tank is filled with sufficient product that the entire exposed tank bottom floor sits fully in contact with the sand infill.

23.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective on the exposed AST external bottom surface, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 27.

Table 27 — AST External Bottom - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, control of	One to three years

	instruments, and measuring of the output voltage and current	
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years[(ii)]
Potential monitoring tubes & PREs	Measurement of 'CP ON' potential	One year
Potential monitoring tubes & PREs	Measurement of 'CP OFF' / polarised potential [(i)]	Three years
Corrosion coupons	Measurement of coupon 'connected' and 'disconnected' potentials. Measurement of coupon currents.	One year
Electrical resistance corrosion probes	Measurement of corrosion rates.	One year

Notes.

(i) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years

24 TECHNICAL REQUIREMENTS – AST INTERNAL

24.1 General

The CP design for the internal wetted/submerged surfaces of above ground storage tanks, shall be based on a permanent impressed current system or a permanent sacrificial anode system, depending on the operational use of the tank:

- Fresh water storage tanks - ICCP systems
- Fresh water storage tanks (small dimensions) - SACP systems
- HC/Oily products storage tanks (with water dropout) - SACP systems

Note:

(i) Use of permanent SACP systems for fresh water storage tanks will be considered where the dimensions of the tank allow for internal protection without need for large 'excessive' quantities of anodes and provision of an impressed current system is not economically viable i.e. protection current requirements are a few amps. (subject to acceptance by COMPANY),

(ii) Potable water storage tanks, storing water for human/animal consumption shall be protected from corrosion by use of a coating system only, certified for use with drinking water. No cathodic protection system shall be applied that may contaminate the potable water,

(iii) Buried vessels used for HC Oily products with a water dropout shall be protected internally using a SACP system as described in this section for HC/Oily products storage tanks.

Permanent ICCP systems shall be based on suspended anodes from cofferdams on the tank roof.

Permanent SACP systems shall be based on sacrificial anodes installed on the bottom of the AST within the water layer, either as 'stand-off' supported on brackets or 'flush' mounted depending on water level heights.

24.2 CP Criteria

The internal AST-to-electrolyte potential is the criterion for evaluating effectiveness of cathodic protection.

Impressed current CP systems shall be designed such that instantaneous "OFF" / Polarised potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the AST internal wetted/submerged surfaces, over its design life, to achieve an Instant "OFF" / Polarised potential over the entire AST internal wetted/submerged surface, equal to or more negative than stated in Table 28 below.

To avoid detrimental effects on the applied coating (disbondment) or on the structure (hydrogen induced stress cracking) due to over protection, Instant "OFF" / Polarised potentials for carbon steel shall not be more negative than the overprotection limit value as stated in Table 28 below.

Table 28 — AST Internal - Protection Criteria for ICCP Systems

ENVIRONMENT	Instantaneous "OFF" / Polarised Potentials, mV w.r.t	
	$Cu/CuSO_4$	Ag/AgCl
Protection potential for steel in aerobic water environment.	-850	-800
Over protection limit for carbon steel in water environment	-1200	-1150

Notes.

(i) Cu/CuSO4 reference cell is used in water environments where chloride content is low

(ii) Ag/AgCl reference cell is used in saline water environments having high chloride content (more than 1000 ppm)

(iii) For sacrificial CP system, ON potential values as per Table 28 above shall be considered.

24.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for AST internal CP systems, based on the different CP systems applied, shall be as follows:

- Permanent ICCP system — 30 years,
- Permanent SACP system — 10 years

Note.

(i) If the normal life of components of the cathodic protection system is shorter than the design life of the equipment or if adequate control of the cathodic protection levels at the beginning and at the end of the design life are technically incompatible, the CONTRACTOR shall include, and justify in CP design, the installation of a system based on this shorter life and shall include methods and instructions for future upgrading of the system.

This may be the case with sacrificial anode systems.

24.4 Anode/Groundbed Parameters

24.4.1 Anodes

Anodes for use in the protection of AST internal wetted/submerged surfaces shall be as follows:

- Mixed metal oxide (MMO) coated titanium tubes or wire (ICCP) - fresh water
- Magnesium alloy anodes (SACP) - fresh water

- Zinc alloy anodes (SACP) - HC/Oily water
- Aluminium alloy anodes (SACP) - HC/Oily water

The MMO/titanium anode shall have the following design parameters:

Table 29 — AST Internal - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Tubular Anode	Design Values
Tubular anode size (min)	25mm dia. X 1000mm long
Titanium (tubular)	ASTM B338, grade 1
Current density (in freshwater)	Max. 100 A/m^2
MMO/Titanium parameters - Wire Anode	**Design Values**
Wire anode size (min)	3.0mm diameter
Titanium (wire)	ASTM B863, grade 1
Current density (in freshwater)	Max. 100 A/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly.

The magnesium alloy anode shall have the following design parameters:

Table 30 — AST Internal - Magnesium Alloy Anode Design Parameters

Magnesium alloy parameters	Design Values
	Std potential
Anode solution potential	-1500 to -1550mVcse
Electrochemical capacity	1100 A-hr/kg
Anode density	1.94g/cm^3
Efficiency	50%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Efficiency values based on an anode current density of approx. 320mA/m2

(iii) Details of anode chemical composition given in Annex I

The zinc alloy anode (ASTM B418 Type I) shall have the following design parameters:

Table 31 — AST Internal - Zinc Alloy Anode Design Parameters

Zinc alloy parameters	Design Values
Anode solution potential < 30°C > 30 to 50°C	 -1030mVssc(sw) -1030mVssc(sw)
Electrochemical capacity < 30°C > 30 to 50°C	 780 A-hr/kg 780 A-hr/kg
Anode density	7.00g/cm^3
Efficiency	90%

Notes.

(i) Design values derived from ISO 15589-2 (Table 5).

(ii) Details of anode chemical composition given in Annex I

(iii) Zinc anode surface temperature shall not exceed 50°C.

The aluminium alloy anode shall have the following design parameters:

Table 32 — AST Internal - Aluminium Alloy Anode Design Parameters

Aluminium alloy parameters	Design Values
Anode solution potential < 30°C 60°C	 -1050mVssc(sw) -1050mVssc(sw)

80°C	-1000mVssc(sw)
Electrochemical capacity < 30°C 60°C 80°C	 2000 A-hr/kg 1500 A-hr/kg 900 A-hr/kg
Anode density	$2.72/cm^3$
Efficiency	95%

Notes.

(i) Design values derived from ISO 15589-2 (Table 5).

(ii) Details of anode chemical composition given in Annex I

(iii) Aluminium anode surface temperature shall not exceed 80°C.

24.4.2 Groundbeds

Anode groundbeds for AST internal protection shall be MMO/Ti type suspended from cofferdams in the tank roof. The anode type of shall be:

- MMO/Ti tubular anodes
- MMO/Ti wire 'piggyback' anodes

Anode cable tails shall comprise, 1 x $16mm^2$ Cu conductor with XLPE primary insulation and PVC outer sheath. Use of XLPE/PVC cables are adequate for tank internal CP systems as fresh water does not contain high chloride levels.

Note. ADNOC have experienced a number of historical failures of piggy back wire anodes. To ensure the integrity and design life of the wire anode system, anode-to-cable connections shall be undertaken by the piggy back wire anode fabricator/manufacturer. All connections shall be tested in accordance with a Company approved ITP specifying He leak tests and resistance tests.

Anode groundbeds located in fresh water shall be designed to have a resistance to remote earth less than 1.0 ohm and fulfil anode current output characteristics under normal electrolyte conditions.

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system

- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- Its location is a close anode to the AST internal surfaces, to provide a uniform distribution of current to the entire wetted/submerged surface of the AST internal
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

Anode groundbeds for sacrificial protection of AST internals shall be based on 'stand-off' or 'flush mounted' anodes on the tank floor. The anode type used dependent on the following:

- Stand-off anodes - where water levels are min. 500mm height and a min. 300mm separation between the bottom of the anode and the tank floor is maintained,
- Flush mounted - where water levels are less than 500mm height

The design of a sacrificial anode cathodic protection system shall be based on the anode current and weight meeting the design requirements.

The design current shall be calculated based on the surface area, design current density at the operating temperature and current allowance. Anode weight shall be calculated based on design current, design life, anode alloy capacity, and efficiency and utilization factor.

The anode current output shall be calculated based on driving voltage and total circuit resistance. Current output shall be more than the design current. It may be necessary to increase the number of anodes to meet the design current output.

24.5 Design Resistivity

Design resistivity values shall be based on the electrolyte resistivity values deteremined during pre-design site surveys.

24.6 Design Current Density

CP design for the internal wetted/submerged surfaces of AST internals, shall be based on either a suspended anode system for an ICCP system in a fresh water tank, or distributed galvanic anodes on the tank floor for a SACP system in a HC tank with a water layer or small fresh water tank.

The CONTRACTOR shall carry out voltage gradient calculations for the ICCP system to determine quantity and spacing of the suspended anodes strings. For the SACP system calculations to determine the quantities of anodes to meet the final design current and the weight/mass requirements shall be undertaken.

The current densities and coating breakdown factors to be applied in the CP design shall as detailed in Table 33.

Table 33 – AST Internal - Current Densities and Coating Breakdown Factors

Anode Environment	Current density for bare steel (mA/m²)
Immersed in fresh water	30
Immersed in saline water	110
Immersed in HC/Oily water	110
Design Period	**Coating breakdown factor for 'final' design**
Initial	1%
Mean	10%

Notes.

(i) Current density value for fresh water derived from NACE SP0388 & SP0196.

(ii) Current density value for HC/Oily water derived from NACE SP0575.

(iii) Current density for saline water applied as for HC/Oily water.

(iv) Coating break down factors derived from NACE SP0388.

(v) Coating breakdown factor for 'mean' design period shall also be applied for 'final' design period.

(vi) Current densities are based on 25°C operating temperature, above 25°C current density values shall be increased by 1mA/m² for each 1°C rise in temperature (derived from DNVGL-RP-B401).

24.7 Coating Breakdown Factor

Coating breakdown factors for AST internals are detailed in Table 33. Application of additional coating breakdown factors are not required.

24.8 Surface Area

Surface area of the AST internal to be afforded cathodic protection shall be based on the total water wetted/submerged internal surface area of the AST.

24.9 Monitoring Facilities

24.9.1 Cable Connection to Tank

The cable connection to the tank shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the structure.

Cable connections shall not be carried out within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All cable connections shall be fully encapsulated to comply with the original coating standards.

The following methods shall be used for cable connections:

Table 34 — AST Internal - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Tank	Welded Pad	Welded Pad

24.9.2 Monitoring Facility Types

Monitoring of the CP system applied to the internal wetted surfaces of fresh water storage tanks (only) shall be based on the following:

- Permanent reference electrodes, three (3) no. installed at 1m above tank floor, midpoint of water depth and 1m below HLL, through a coffer dam on the tank roof close to the tank edge,
- Portable reference electrode cofferdam, located on roof of tank close to the tank edge, to allow insertion of a portable reference electrode.

The roof top cofferdams for permanent and portable reference electrodes shall be located nom. 100mm from tank edge.

The type of permanent reference electrode to be used shall be either Cu/CuSO4 or Ag/AgCl and be suitable for long term operation in the medium stored in the tank. The cable tails from each reference electrode shall be routed across the tank roof and down the side of the tank to a monitoring test box located at ground level.

Connection of the tank main negative drainpoint cable and negative monitoring cable shall be by welded pad on the side of the tank wall. The negative monitoring cable shall be routed from the welded connection pad to the monitoring test box. The cable connections at the welded connection pad shall be encapsulated using epoxy.

Monitoring of internal CP system for HC/oily tanks with a water 'dropout' layer is not required, as contamination of the reference electrode from the HC/oil can affect the operational integrity of the reference electrodes.

24.10 Interference

24.10.1 DC Interference

DC interference is not considered an issue for AST internal CP systems.

24.10.2 AC Interference

AC interference is not considered an issue for AST internal CP systems.

24.11 Electrical Isolation

Electrical isolation is not required for the pipework coming off the ASTs as the cathodic protection systems applied: suspended anode for the internal wetted/submerged surfaces, are based on a close anode CP system which will ensure current flow preferentially to the tank internal surface.

24.12 Anode Installation Procedure

24.12.1 Impressed Current CP System

Provision of an impressed current CP system for tank internal surfaces shall be applied to water storage tanks (excluding potable water) without any HC presence/contamination.

Potable water storage tanks, storing water for human/animal consumption shall be protected from corrosion by use of a coating system only, certified for use with drinking water. No cathodic protection system shall be applied that may contaminate the potable water.

The ICCP system shall be based on suspended anodes from cofferdams on the tank roof. The anodes shall be wire or tubular types of anodes and shall be arranged such that uniform current distribution shall ensure potentials in accordance with the protection criteria (Table 28) are achieved on all of the submerged/wetted steel surfaces.

Suspended anodes / permanent reference electrodes shall be supported by a PVC coated stainless steel rope of minimum 5 mm diameter. Anodes / permanent reference electrodes shall not be self-supporting.

Appropriate ballast weights shall be installed for suspended anodes / reference electrodes to keep them stationary while the fluid is moving inside the tank.

Cofferdams on the tank roof, provided for the tie-off of support ropes for the suspended anode and permanent reference electrode, shall also allow the suspended anodes / permanent reference electrodes to be removed, replaced or inspected without entering the tank. All cofferdams shall have removable, gasket covers.

An additional cofferdam shall be installed on the tank roof (nom. 100mm from tank edge) for insertion of a portable reference electrode.

Each anode suspended string shall be terminated in a junction box located adjacent to the respective anode cofferdam, where anode power feed cables shall also be terminated and bonded to the anode cable tail. Underwater splices of cables are not permitted.

Each anode power feed cable and permanent reference electrode cable tail shall be run in galvanized and painted conduits along the tank roof and then down the side to ground level to terminate in junction/test boxes.

Anode junction boxes shall house in each anode circuit shunts to permit current measurement and grid coil resistors to permit balancing of current output from the anodes. A separate monitoring test box shall house the permanent reference electrode cables and a monitoring negative cable.

Junction boxes shall be installed at ground level to ensure safe operation and monitoring without need for frequent inspection on tank roof tops.

Connection of the tank main negative drainpoint cable and negative monitoring cable shall be by welded pad on the side of the tank wall. The negative monitoring cable shall be routed from the welded connection pad to the monitoring test box. The cable connections at the welded connection pad shall be encapsulated using epoxy.

Suspended anodes shall be supported from the roof in a vertical position for optimum current distribution. Installation shall not require emptying, wall penetrations below the high water line or the use of pressure fittings. The design shall ensure that electrical shorts do not occur between the anode and support system, the tank, etc., for the design service life.

Unless otherwise approved by the COMPANY, the distance between the anode surface and the tank surface shall not be less than one meter. The anode system shall be designed to prevent electrical shorting to the tank.

The anode system shall provide and maintain uniform distribution of current without exceeding the potential limits stated in the cathodic protection criteria. The anode system shall have lowest possible circuit resistance.

Voltage attenuation shall be less than 10% at the anode end opposite from the anode to power feed cable connection.

Reference electrodes shall be located approximately at equal distance from the anodes and close to the intersection of floor and shell. A magnet secured to a reference electrode cell shall be used to maintain the 10 mm distance from tank surface. The straight line spacing between reference electrodes shall not exceed 10 metres and the minimum number of reference electrodes per tank shall be two.

Automatic controls shall be installed to adjust the output of the rectifiers based on potential readings of the permanent reference electrodes. The system shall be also automatically adjustable for all variables except IR drop error.

24.12.2 Sacrificial Anode CP System

Internal sacrificial protection of ASTs shall be applied where low levels of water collect within the structure, as drop-out from stored HC or oily products.

Sacrificial anodes may also be considered for fresh water (non-potable) tanks, dependent on the design calculations indicating that large ‘excessive ‘ numbers of anodes would **not** be needed to provide the required protection.

The sacrificial CP system shall be designed for a 10 year life, with provision for replacement of anodes after 10 years.

Anodes shall be based on zinc alloy (for temperatures up to 50°C) or aluminium alloy (for temperatures up to 80°C).

Where water levels allow (min. 500mm height), anodes shall be installed supported on stand-off brackets with a minimum 300mm separation between the bottom of the anode and the structure floor.

Where water levels are less than 500mm height then flush mounted anodes shall be considered. The underside of the anode in contact with the structure floor is to be coated with an appropriate coating (Manufacturer's standard).

Anode stand-off brackets and flush mounted anodes shall be directly welded onto connection pads pre-welded to the tank internal floor. The weld connection pad shall be of the same material as the tank steel and after welding all required welding tests and inspections shall be undertaken to ensure the integrity of the tank steel structure.

Prior to welding of the stand-off brackets or flush mounted anodes, the weld connection pad shall be cleaned (by hand tools) to remove any rust / debris to bright metal. Care shall be taken during this operation to ensure no damage to the tank internal surface.

After welding of the stand-off bracket or flush mounted anode to the weld connection pad, the weld shall be inspected according to COMPANY requirements and then coated using the same coating system as applied to the tank internal surfaces. Care shall be taken to ensure that anode surfaces are not contaminated with the coating system.

24.13 Pre-Commissioning and Commissioning Procedures

24.13.1 Impressed Current CP System

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to tank structure tests of the anode system (to ensure no electrical shorting between anode and tank structure), calibration checks of permanent reference electrodes.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for energizing cathodic protection hardware

(c) Procedure for testing and adjustment of the AST internal-to-electrolyte potential

(d) Requirements for polarization of the AST internal

(e) Procedures for full ON / OFF potential surveys

(f) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the AST

(g) Required format of the commissioning report

(h) Procedure for clearing the Punch List items

Note.

Pre-commissioning and commissioning of the tank internal ICCP system shall only be undertaken when the tank is filled with sufficient product that the anodes, PREs and internal surfaces of the tank are submerged.

24.13.2 Sacrificial Anode CP System

Pre-commissioning of tank internal SACP systems shall include electrical continuity tests of the welded/bolted connection between the anode and the tank and visual inspection of the anode surface to ensure it is clean of any contamination e.g. paint splatter.

Commissioning of the internal SACP system, can only be undertaken once the tank is filled with product, submerging the anodes, PREs (if applicable) and internal surfaces of the tank. At this point the sacrificial CP system will be activated.

For freshwater tanks, commissioning procedures for the SACP system shall include as a minimum:

(a) Requirements for polarization of the AST internal

(b) Procedures for full ON potential surveys

(c) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the AST

(d) Required format of the commissioning report

(e) Procedure for clearing the Punch List items

Note:

For HC/oily water storage tanks, reference electrodes are not installed (due to potential contamination) and therefore commissioning of the CP system cannot be inspected.

24.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective on the wetted/submerged AST internal surface, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 35

Table 35 – AST Internal - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, control of instruments, and measuring of the output voltage and current	One to three years
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years(ii)
Potential monitoring with PREs	Measurement of 'CP ON' potential	One year
Potential monitoring with PREs and portable REs	Measurement of 'CP OFF' / polarised potential (i)	Three years

Notes.

(i) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years,

(ii) Monitoring of the internal CP system for HC/oily vessels with a water 'dropout' layer is not required, as contamination of reference electrodes from the HC/oil can affect the operational integrity of the electrodes. Condition of the anodes and the internal surfaces shall be inspected during routine maintenance shut-downs, when the tank/vessel can be drained and inspected

25 TECHNICAL REQUIREMENTS — BURIED TANKS / VESSELS

25.1 General

The CP design for the external surfaces of buried tanks/vessels, shall be based on a permanent impressed current system. designed around a 'close anode' system installed around the tank/vessel in the sand infill surrounding the structure.

The buried tanks/vessels covers design criteria, parameters and calculations of cathodic protection systems used for the external protection of tanks/vessels installed below ground or in concrete pits with a sand infill.

Note:

No CP system is required if the tank/vessel is installed in a concrete pit exposed to atmosphere i.e. no sand infill in pit around tank/vessel.

25.2 CP Criteria

The buried tank/vessel-to-soil potential is the criterion for evaluating effectiveness of cathodic protection.

Impressed current CP systems shall be designed such that instantaneous "OFF" / Polarised potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the external surface of the buried tank/vessel, over its design life, to achieve an Instant "OFF" / Polarised potential over the entire buried tank/vessel external surface, equal to or more negative than stated in Table 36 below. To avoid detrimental effects on the applied coating (disbondment) or on the structure (hydrogen induced stress cracking) due to over protection, Instant "OFF" / Polarised potentials for carbon steel shall not be more negative than the overprotection limit value as stated in Table 36 below.

The protection potential values stated for aerobic environments shall also apply to anaerobic environments where soil investigation has confirmed the presence of active sulphate reducing bacteria.

Table 36 — Buried Tanks/Vessels - Protection Criteria for ICCP Systems

ENVIRONMENT	Instantaneous "OFF" / Polarised Potentials, mV w.r.t	
	$Cu/CuSO_4$	$Zn/ZnSO_4$
Protection potential for steel in aerobic/anaerobic soil/sand environment.	-950	+150
Over protection limit for carbon steel in soil/sand environment	-1200	- 100

Notes.

(i) Cu/CuSO4 reference cell is used in normal soil where chloride content is low

(ii) Zn/ZnSO4 reference cell is used in soils applications where chloride content is low (less than 1000ppm) and long life operation/usage is required. These are considered the preferred option for buried tank/vessel monitoring.

(iii) 100 mV polarization criteria may be considered (subject to acceptance by COMPANY) in special cases if it is not possible to achieve the potentials listed in Table 36.

25.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for buried tanks/vessels external CP systems, shall be as follows:

- Permanent ICCP system – 30 years,

25.4 Anode/Groundbed Parameters

25.4.1 Anodes

Anodes for use in the protection of buried tanks/vessels external surfaces shall be as follows:

- Mixed metal oxide (MMO) coated titanium tubes or wire (ICCP)

The MMO/titanium anode shall have the following design parameters:

Table 37 – Buried Tanks/Vessels - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Tubular Anode	**Design Values**
Tubular anode size (min)	25mm dia. X 1000mm long
Galvanised Steel canister	150mm dia. X 1500mm long
Titanium (tubular)	ASTM B338, grade 1
Current density (in carbonaceous backfill)	Max. 50 A/m^2
Current density (in calcined petroleum)	Max. 100 A/m^2
MMO/Titanium parameters - Wire Anode	**Design Values**
Wire anode size (min)	3.0mm diameter
Geotextile sock	38mm diameter
Titanium (wire)	ASTM B863, grade 1

Current density (in calcined petroleum)	Max. 100 A/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly.

25.4.2 Groundbeds

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system
- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- Its location is a close anode to the AST external bottom, to provide a uniform distribution of current to the entire exposed surface of the AST external bottom
- The risk of causing harmful interference on other buried structures is minimized
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

Anode groundbeds for the external protection of buried tanks/vessels shall be installed in a ‘close anode’ system surrounding the buried tank/vessel. For new vessels where it is feasible to install the anodes before backfill operations like tanks/vessels buried within concrete reinforced pits, piggy backed MMO anodes are preferred. In situations where this is not possible or for existing vessels, canistered MMO anodes shall be used.

MMO/Ti wire ‘piggyback’ anodes shall be encased in a geotextile sock filled with calcined petroleum coke.

MMO/Ti tubular anodes shall be encased in a galvanised steel (GS) canister and filled with calcined petroleum coke backfill.

Note. ADNOC have experienced a number of historical failures of piggy back wire anodes. To ensure the integrity and design life of the wire anode system, anode-to-cable connections shall be undertaken by the piggy back wire anode fabricator/manufacturer. All connections shall be tested in accordance with a Company approved ITP specifying He leak tests and resistance tests.

25.5 Design Resistivity

For tanks/vessels buried within a concrete reinforced pit with sand infill, the sand infill shall be mechanically washed sand conforming to ASTM C778 type “20-30 sand” with the following properties:

- Maximum Chlorides (Cl-) 300ppm
- Maximum Sulphates (SO42-) 200ppm
- pH between 6.5 and 8.5

Resistivity values for the sand infill shall be measured, by soil box, from a sample taken of the infill to be used. This shall be used in the design calculations. Where this is not feasible at the start of design, then the following assumptions shall be used for resistivity values and applied in the design calculations:

- Maximum sand resistivity : 50,000 ohm.cm
- Minimum sand resistivity : 15,000 ohm.cm

The CP system shall be designed to be able to operate in both resistivity conditions stated above.

For tanks/vessels not installed in a concrete pit, and where washed sand (ASTM C778 type) is not used, the design resistivity values shall be based on the surrounding soil/sand resistivity measurements recorded during pre-design site surveys.

25.6 Design Current Density

The CP design for the external surfaces of buried tank and vessels shall be based on a 'close anode' system installed around the tank/vessel in the sand infill surrounding the structure.

Note. For new structures the sand infill shall be as per that specified in sec. 25.5.

The CONTRACTOR shall carry out voltage gradient and attenuation calculations to determine the spacing of the anodes around the structure.

The current densities and coating breakdown factors to be applied in the CP design shall be as detailed in Table 38.

Table 38 – Buried Tanks/Vessels - Current Densities and Coating Breakdown Factors

Current density for bare steel (mA/m²)	Coating breakdown factor for 'final' design
20	10%

Notes.

(i) Current densities are based on 30°C operating temperature, above 30°C current density values shall be increased by 25% per 10°C rise in temperature.

25.7 Coating Breakdown Factors

Coating breakdown factors for buried tanks/vessels are detailed in Table 38. Application of additional coating breakdown factors are not required.

25.8 Surface Area

Surface area of the buried tanks/vessels to be afforded cathodic protection shall be based on the total exposed tank/vessel external surface area in contact with the surrounding sand infill.

25.9 Monitoring Facilities

25.9.1 Cable Connection to Tank/Vessel

The cable connection to the buried tank/vessel shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the structure.

Cable connections shall not be carried out within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All buried cable connections shall be fully encapsulated to comply with the original coating standards.

The following methods shall be used for cable connections:

Table 39 – Buried Tanks/Vessels - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Tank	Welded Pad	Welded Pad

25.9.2 Monitoring Facility Types

All new buried tanks/vessels shall have two vertical potential monitoring ducts. The ducts shall be installed away from the anodes. The ducts shall extend from the top to the bottom of the tank/vessel. An end cap shall be provided at the bottom. The duct shall be slotted and covered with geo-textile cloth. A removable cover shall be provided at the top of duct.

In addition to this two (2) no. permanent reference electrodes, corrosion coupons and electrical resistance corrosion probes shall be installed for each vessel.

Permanent reference electrodes shall be zinc/zinc sulfate type, one located at the bottom of the vessel, and on the side of the vessel. Corrosion coupons will be laid adjacent to the PRE. The corrosion probe shall be located on the side of the vessel, where the influence of oxygen will be higher.

All cable tails from monitoring equipment will be routed to and terminated in an above ground monitoring test box located at the head of the buried vessel. Vessel negative monitoring cables (connected to the tank/vessel by welded pad) shall also be terminated within the monitoring test box.

25.10 Interference

25.10.1 DC Interference

For tanks/vessels installed within a concrete pit, DC interference from CP systems of adjacent structures is not considered an issue and no action is required. For potential dc interference from the buried tank/vessel

CP system on steel reinforcing in the concrete pit walls, this can be alleviated by the application of a barrier coating system to the internal surfaces of the concrete wall.

For directly buried tanks/vessels (not in a concrete pit) CP systems of adjacent structures can interfere with the protected structure.

DC interference can lead to accelerated corrosion of affected structure.

The CONTRACTOR shall investigate possible sources of detrimental DC stray currents and include proposals in the design on how to mitigate the effect of such stray currents on the protected structure.

CONTRACTOR shall carry out a stray current survey at the time of commissioning.

For interaction effects on secondary structures as a result of the CP system on the protected structure, the following shall be applied:

(a) On secondary structures without a CP system, maximum positive potential change on any part of the secondary structure, resulting from interaction, should not exceed 20 mV. In case a positive swing of more than 20 mV, mitigation measures shall be adopted by the CONTRACTOR

(b) On secondary structures with a CP system, unacceptable interference shall be deemed when the 'Polarized' potential on the secondary structure does not achieve the protection potential range as per Table 36 .

Mitigation measures include:

(a) Prevention of pickup of stray current by improved isolation or shielding

(b) Re-distribution of CP current sources, adjustment of current output from mutually interfering CP power sources

(c) Installation of metallic bonds between affected structures

(d) Application of unidirectional control devices such as diodes or reverse current switches

(e) Use of galvanic anodes on the anodic section

25.10.2 AC Interference

AC interference is not considered an issue for buried tanks/vessels.

25.11 Electrical Isolation

For directly buried tanks/vessels provided with an external cathodic protection system, the following philosophy shall be applied:

(a) The tank/vessel shall be electrically isolated at all pipework using isolating joints/flanges,

(b) If tank/vessel is connected to an earthing system, solid state polarization cell shall be provided between tank/vessel and earthing to prevent current drain to earthing

25.12 Anode Installation Procedure

Distributed anodes or piggy backed anodes shall be used in the plants for the protection of tanks/vessels. This helps in avoiding the current drain to foreign structures.

The depth of the distributed anodes shall be based on the soil resistivity, and spacing shall be governed by the voltage gradient.

The number or length of anodes required shall be calculated based on design current and current capacity of each anode.

Anodes shall be MMO/Ti tubular anodes encased in a galvanised steel (GS) canister filled with calcined coke backfill or MMO/Ti wire anodes piggy backed on to a power cable and encased in a geotextile sock filled with calcined coke.

For new vessels where it is feasible to install the anodes before backfill operations like tanks/vessels buried within a concrete reinforced pit, piggy backed MMO anodes are preferred. In situations where this is not possible or for existing tanks/vessels directly buried in sand/soil, canistered MMO anodes shall be used.

Characterises for sand pads surrounding the buried tanks/vessels shall be as per described in sec.25.5.

For CP systems based on MMO/Ti tubular canistered anodes, these shall be installed vertically around the periphery of the buried tank/vessel. It shall be ensured that all sections of the tank/vessel receive the current from the installed anodes and none of area is shielded or left unprotected.

Any pipework connected to the vessel shall be electrically isolated (sec.25.11).

Two welded pads shall be provided for the termination of the negative drain cable and monitoring cable.

The anode junction box shall be preferentially located in the safe area. However when it is not feasible, the junction box enclosure shall be suitable for the hazardous area. The T/R unit shall be located in a safe area.

Note:

No CP system is required if the tank/vessel is installed in a concrete pit exposed to atmosphere i.e. no sand infill in pit around vessel.

The recommended minimum sizing for anodes shall be:

(i) MMO tubular: 25mm diameter x 1000mm length,

(ii) GS canister: 150mm diameter x 1500mm length,

(iii) MMO wire: 3.0mm diameter

(iv) Geotextile sock : 38mm diameter

Power cables for the canistered tubular anodes and ‘piggyback’ wire anode shall have a primary insulation of XLPE and an outer sheath shall be HMWPE. The cable conductor shall be stranded copper and the minimum size of cable shall be 1x16 mm^2.

Note: XLPE / PVC cables are considered adequate in chloride free sand.

Prior to construction/installation of the buried tank/vessel CP system, resistivity measurements of the sand infill shall be taken and confirmed against the assumed design values. Any measured values outside of this range shall be brought to the attention of the COMPANY for evaluation of possible impact on CP design.

25.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to tank/vessel structure tests of the anode system (to ensure no electrical shorting between anode and tank structure), calibration checks of permanent reference electrodes.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for energizing cathodic protection hardware

(c) Procedure for testing and adjustment of the buried tank/vessel-to-soil/sand potential

(d) Requirements for polarization of the external surface of the buried tank/vessel

(e) Procedures for full ON / OFF potential surveys

(f) Procedures for electrical isolation testing

(g) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the buried tank/vessel

(h) Required format of the commissioning report

(i) Procedure for clearing the Punch List items

25.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective on the exposed external buried tank/vessel surface, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 40.

Table 40 — Buried Tanks/Vessels - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, control of instruments, and measuring of the output voltage and current	One to three years
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years[(ii)]
Potential monitoring tubes & PREs	Measurement of 'CP ON' potential	One year
Potential monitoring tubes & PREs	Measurement of 'CP OFF' / polarised potential [(i)]	Three years
Corrosion coupons	Measurement of coupon 'connected' and 'disconnected' potentials. Measurement of coupon currents.	One year
Electrical resistance corrosion probes	Measurement of corrosion rates.	One year

Notes.

(i) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years.

26 TECHNICAL REQUIREMENTS – SHORT BURIED SECTIONS OF PIPELINES

26.1 General

The CP design for short buried pipeline sections shall be based on a permanent sacrificial anode CP system.

The short buried sections of pipelines covers design criteria, parameters and calculations of cathodic protection systems used for buried sections of normally above ground flowlines, occurring at crossings with roads or other foreign services.

26.2 CP Criteria

The pipeline to soil potential is the criterion for evaluating effectiveness of cathodic protection.

Sacrificial anode CP systems shall be designed such that "CP ON" potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the pipeline, over its design life, to achieve an "ON" potential over the entire buried section of pipeline, equal to or more negative than stated in Table 41 below.

Some corrosion resistant steels and high strength steels (e.g. Duplex stainless steels) are more susceptible to hydrogen induced stress cracking than carbon steel. The protection criteria for structures made of such materials shall be determined on a case by case basis. This is also applicable when designing a cathodic protection system for a pipeline crossing or approaching another pipeline made of such a material.

The protection potential values stated for aerobic environments shall also apply to anaerobic environments where soil investigation has confirmed the presence of active sulphate reducing bacteria.

Table 41 – Short Buried Sections of Pipelines - Protection Criteria for SACP Systems

ENVIRONMENT	"ON" Potentials, mV w.r.t		
	$Cu/CuSO_4$	Ag/AgCl	$Zn/ZnSO_4$
Protection potential for steel in aerobic/anaerobic soil environment.	-950	-900	+150
Over protection limit for Duplex Stainless Steel (DSS) / SS	-1100	-1050	0

Notes.

(i) Cu/CuSO4 reference cell is used for pipelines in normal soil where chloride content is low

(ii) Ag/AgCl reference cell is used in soils having high chloride content (more than 1000 ppm)

(iii) Zn/ZnSO4 reference cell is used in soils applications for special monitoring purposes only

(iv) For sacrificial CP system where ‘AS-FOUND’ potential of flowline is already -950 mVcse or more negative due to interference or influence of other CP systems, protection criteria from the installed CP system shall result in a net flow of current to the pipeline and a negative polarization observed

(v) Over protection limits stated for duplex stainless steels are based on Instant “OFF” / Polarised potentials.

26.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for short buried sections of pipeline CP systems, shall be as follows:

- Permanent SACP system – 20 years,

Note.

(i) If the normal life of components of the cathodic protection system is shorter than the design life of the equipment or if adequate control of the cathodic protection levels at the beginning and at the end of the design life are technically incompatible, the CONTRACTOR shall include, and justify in CP design, the installation of a system based on this shorter life and shall include methods and instructions for future upgrading of the system.

This may be the case with sacrificial anode systems.

(ii) Sacrificial CP system based on magnesium anodes, generally have an operating life expectancy of upto 10years. Where magnesium anodes are used for permanent SACP systems, measures shall be incorporated for anode replacement after 10 years to ensure the required 20 year design life is achieved.

26.4 Anode/Groundbed Parameters

26.4.1 Anodes

Anodes for use in the protection of short buried sections of pipelines shall be as follows:

- Magnesium alloy anodes (SACP)
- Zinc alloy anodes (SACP)

The magnesium alloy anode shall have the following design parameters:

Table 42 — Short Buried Sections of Pipelines - Magnesium Alloy Anode Design Parameters

Magnesium alloy parameters	Design Values	
	Std potential	Hi-potential
Anode solution potential	-1500 to -1550mVcse	-1750 to -1770mVcse
Electrochemical capacity	1100 A-hr/kg	1100 A-hr/kg
Anode density	1.94g/cm^3	1.94g/cm^3
Efficiency	50%	50%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Annex I for details)

(iii) Efficiency values based on an anode current density of approx. 320mA/m2

(iv) Details of anode chemical composition given in Annex I

(v) Magnesium anodes should not be used if the resistivity of the electrolyte is higher than 15,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met

The zinc alloy anode (ASTM B418 Type II) shall have the following design parameters:

Table 43 — Short Buried Section of Pipelines - Zinc Alloy Anode Design Parameters

Zinc alloy parameters	Design Values
Anode solution potential	-1100mVcse
Electrochemical capacity	738 A-hr/kg
Anode density	7.00g/cm^3
Efficiency	90%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Annex I for details)

(iii) Details of anode chemical composition given in Annex I

(iv) Zinc anodes should not be used if the resistivity of the electrolyte is higher than 1,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met.

26.4.2 Groundbeds

Sacrificial CP systems shall be used for the permanent protection of short buried pipelines.

The design of a sacrificial anode cathodic protection system shall be based on the anode current and weight meeting the design requirements.

The design current shall be calculated based on the surface area, design current density at the operating temperature and current allowance. Anode weight shall be calculated based on design current, design life, anode alloy capacity, and efficiency and utilization factor.

The anode tail cable shall be a 1x10 mm^2 Cu/XLPE/PVC red cable (where applicable).

The anode current output shall be calculated based on driving voltage and total circuit resistance. Current output shall be more than the design current. It may be necessary to increase the number of anodes to meet the design current output.

26.5 Design Resistivity

Design resistivity values shall be based on the soil resistivity measurements recorded during pre-design site surveys.

26.6 Design Current Density

The CP design for short buried sections of normally above ground flowlines, occurring at crossings with roads or other foreign services, shall be based on a permanent sacrificial anode CP system.

The CONTRACTOR shall carry out the SACP system calculations to determine the quantities of anodes to meet the mean and final design currents and the weight/mass requirements.

The current density values take into account coating deterioration during the design life of the pipeline.

The current density values to be applied in the CP design shall be as detailed in Table 44 .

Table 44 — Short Buried Section of Pipelines - Design Current Densities for Different Flowline Coatings

Type of coating	Current density for 'final' design mA/m²
3LPE or 3LPP	0.02
FBE	0.2
Liquid epoxy, Coal tar or bituminous coating	0.3

Notes.

(i) Values derived from ISO 15589-1:2015 Table 3.

(ii) Final current density values are based on the maximum 'optimized' design values and are applicable for the design of sacrificial anodes for permanent CP systems.

(iii) The values given in Table 44 account for the short buried section of pipeline operating at not more than 30°C temperatures. Where pipeline operating temperatures exceed 30°C a temperature correction factor shall be applied: current density value shall be increased by 25% for each 10°C rise in operating temperature above 30°C.

26.7 Coating Breakdown Factor

Current density values detailed in Table 44 include for coating deterioration during the design life of the short buried section of pipeline. Application of additional coating breakdown factors are therefore not required.

26.8 Surface Area

Surface area of the short buried section of pipeline to be afforded cathodic protection shall be based on the total buried pipeline surface area.

26.9 Monitoring Facilities

26.9.1 Cable Connection to Pipeline

The cable connection to the pipeline shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to pipeline and structure.

Cable connections shall not be carried out on bends or within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All below grade cable connections shall be fully encapsulated to comply with the original coating standards. A holiday test shall be conducted before backfilling.

The following methods shall be used for cable connections:

Table 45 — Short Buried Section of Pipelines - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Existing Pipeline / Piping	N/A	Pin Brazing
New Pipeline / Piping	N/A	Welded Pad

Notes.

(i) The cable shall be looped around the pipe to avoid damage to the connections by accidental pulling of the cable.

26.9.2 Monitoring Facility Types

At each buried section of pipeline, a monitoring test post shall be installed on the downstream side. For buried sections having a length of more than 10m, two monitoring test posts, one at each side shall be provided.

Test facilities shall be above ground conduits with a terminal head/box on top.

The test facility shall contain a correctly sized shunt to monitor anode currents and a variable control resistor to control the anode current (to enhance anode life) and facilitate installation of new anodes in the future without touching the hydrant.

26.10 Interference

26.10.1 DC Interference

DC interference is not considered an issue for short buried sections of pipelines.

26.10.2 AC Interference

AC interference is not considered an issue for short buried sections of pipelines.

26.11 Electrical Isolation

For surface lines (flowlines) buried for short sections e.g. at road crossings, a separate CP system based on a sacrificial CP system shall be provided for each buried section. Electrical isolation is recommended only at each end of the flowline and not at each buried section.

26.12 Anode Installation Procedure

All new buried sections of essentially above ground pipelines and flowlines, such as at road / track / fence crossings, shall be coated and protected with a CP system. This shall also be applicable to the surface flowlines that are covered by new pipelines / ROW of new pipelines.

The sacrificial CP system shall be designed for a 20 year life (see sec. 26.3), with provision for replacement of anodes after 10 years.

Anodes shall be based on pre-packaged zinc or magnesium alloy type.

The type of the anode to be selected depends upon the environmental conditions and shall be selected as per the table below. These can be summarized as under:

Table 46 — Short Buried Section of Pipelines - Sacrificial Anode as Function of Soil Resistivity

Sacrificial Anode	Soil Resistivity (Ohm.cm)
Zinc (Pre-packaged)	<1000
Magnesium (Pre-packaged)	>1000

Anode weight shall be calculated based on design current, design life, anode alloy capacity, efficiency and utilization factor. The anode tail cable shall be 1x10 mm^2 Cu/XLPE/PVC red cable.

Anodes shall be installed horizontally / vertically, alongside the buried pipeline, at / below invert depth and with a 1-2m separation. Anode cable tails shall be terminated within the test facilities provided.

The test post shall be provided with a resistor and shunt to control and monitor anode current output.

A watering arrangement shall be provided to periodically water the anode (s).

26.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include calibration checks of permanent reference electrodes (if applicable).

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for connection of cathodic protection sacrificial anodes

(c) Procedure for testing and adjustment of pipeline/flowline-to-soil potential

(d) Requirements for polarization of the buried pipeline/flowline

(e) Procedures for full ON potential surveys

(f) Procedures for electrical isolation testing

(g) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the short section of buried pipeline/flowline

(h) Required format of the commissioning report

(i) Procedure for clearing the Punch List items

26.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the short buried section of pipeline/flowline, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 47.

Table 47 — Short Buried Sections of Pipelines - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years[(ii)]
Galvanic anode station	Visual check of the stations and measure the ‘CP ON’ pipeline/flowline-to-soil potential	One year
Galvanic anode station	Comprehensive functional tests of the galvanic station e.g. resistor setting, efficiency of the bonding connection and measurement of the ‘CP ON’ pipeline/flowline-to-soil potential	Three years

Notes.

(i) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years

27 TECHNICAL REQUIREMENTS — BURIED CASINGS

27.1 General

The use of cased crossings shall be avoided to the extent possible. However, if casings are used and they are metallic, then protection of the metallic pipeline casings shall be based on a permanent sacrificial anode CP system.

In addition, for metallic carrier pipes, supplementary protection for the section of carrier pipe within the metallic casing shall be provided.

The section buried casings covers design criteria, parameters and calculations of cathodic protection systems used for buried metallic casings occurring at crossings with roads.

27.2 CP Criteria

The casing-to-soil potential is the criterion for evaluating effectiveness of cathodic protection.

Sacrificial anode CP systems shall be designed such that "CP ON" potentials can be measured for assessing the CP system performance.

CP systems shall be designed to provide sufficient current to the buried metallic casing, over its design life, to achieve an "ON" potential over the entire buried section of casing, equal to or more negative than stated in below.

The protection potential values stated for aerobic environments shall also apply to anaerobic environments where soil investigation has confirmed the presence of active sulphate reducing bacteria.

Table 48 — Buried Casings - Protection Criteria for SACP Systems

ENVIRONMENT	"ON" Potentials, mV w.r.t	
	$Cu/CuSO_4$	Ag/AgCl
Protection potential for steel in aerobic/anaerobic soil environment.	-950	-900

Notes.

(i) Cu/CuSO4 reference cell is used for pipelines in normal soil where chloride content is low

(ii) Ag/AgCl reference cell is used in soils having high chloride content (more than 1000 ppm)

27.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for buried metallic casing CP systems, shall be as follows:

- Permanent SACP system — 20 years,

Note.

(i) If the normal life of components of the cathodic protection system is shorter than the design life of the equipment or if adequate control of the cathodic protection levels at the beginning and at the end of the design life are technically incompatible, the CONTRACTOR shall include, and justify in CP design, the installation of a system based on this shorter life and shall include methods and instructions for future upgrading of the system.

This may be the case with sacrificial anode systems.

(ii) Sacrificial CP system based on magnesium anodes, generally have an operating life expectancy of upto 10years. Where magnesium anodes are used for permanent SACP systems, measures shall be incorporated for anode replacement after 10 years to ensure the required 20 year design life is achieved.

27.4 Anode/Groundbed Parameters

27.4.1 Anodes

Anodes for use in the protection of buried metallic casings shall be as follows:

- Magnesium alloy anodes (SACP)
- Zinc alloy anodes (SACP)

The magnesium alloy anode shall have the following design parameters:

Table 49 — Buried Casings - Magnesium Alloy Anode Design Parameters

Magnesium alloy parameters	Design Values	
	Std potential	Hi-potential
Anode solution potential	-1500 to -1550mVcse	-1750 to -1770mVcse
Electrochemical capacity	1100 A-hr/kg	1100 A-hr/kg
Anode density	1.94g/cm^3	1.94g/cm^3
Efficiency	50%	50%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Annex I for details)

(iii) Efficiency values based on an anode current density of approx. 320mA/m2

(iv) Details of anode chemical composition given in Annex I

(v) Magnesium anodes should not be used if the resistivity of the electrolyte is higher than 15,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met

(vi) Supplementary protection of metallic carrier pipes routed through the casing shall use magnesium ribbon anodes, where the carrier operating temperature is higher than 55°C.

The zinc alloy anode (ASTM B418 Type II) shall have the following design parameters:

Table 50 — Buried Casings - Zinc Alloy Anode Design Parameters

Zinc alloy parameters	Design Values
Anode solution potential	-1100mVcse
Electrochemical capacity	738 A-hr/kg
Anode density	7.00g/cm^3
Efficiency	90%

Notes.

(i) Design values derived from NACE Corrosion Engineers Reference Book 3rd Ed

(ii) Anode properties based on anodes installed in a suitable chemical backfill (see Annex I for details)

(iii) Details of anode chemical composition given in Annex I

(iv) Zinc anodes should not be used if the resistivity of the electrolyte is higher than 1,000 ohm.cm, unless the engineering evaluation or field test confirm that the design requirements can still be met.

(v) Supplementary protection of metallic carrier pipes routed through the casing shall use zinc ribbon anodes, where the carrier operating temperature is lower than 55°C

27.4.2 Groundbeds

Sacrificial CP systems shall be used for the permanent protection of buried metallic casings.

The design of a sacrificial anode cathodic protection system shall be based on the anode current and weight meeting the design requirements.

The design current shall be calculated based on the surface area, design current density at the operating temperature and current allowance. Anode weight shall be calculated based on design current, design life, anode alloy capacity, and efficiency and utilization factor.

The anode tail cable shall be a 1x10 mm^2 Cu/XLPE/PVC red cable (where applicable).

The anode current output shall be calculated based on driving voltage and total circuit resistance. Current output shall be more than the design current. It may be necessary to increase the number of anodes to meet the design current output.

27.5 Design Resistivity

Design resistivity values shall be based on the soil resistivity measurements recorded during pre-design site surveys.

27.6 Design Current Density

The CP design for buried metallic casings occurring at crossings with roads shall be based on a permanent sacrificial anode CP system.

The CONTRACTOR shall carry out the SACP system calculations to determine the quantities of anodes to meet the mean and final design currents and the weight/mass requirements.

The current density values take into account coating deterioration during the design life of the pipeline.

The current density values to be applied in the CP design shall be as detailed in Table 51.

Table 51 — Buried Casings - Design Current Densities for Different Flowline Coatings

Type of coating	Current density for 'final' design mA/m^2
3LPE or 3LPP	0.02
FBE	0.2
Liquid epoxy, Coal tar or bituminous coating	0.8

Notes.

(i) Values derived from ISO 15589-1:2015 Table 3.

(ii) Final current density values are based on the maximum 'optimized' design values and are applicable for the design of sacrificial anodes for permanent CP systems.

(iii) The values given in Table 51 account for the buried casing operating at not more than 30°C temperatures. Where casing operating temperatures exceed 30°C a temperature correction factor shall be applied: current density value shall be increased by 25% for each 10°C rise in operating temperature above 30°C.

27.7 Coating Breakdown Factor

Current density values detailed in Table 51 include for coating deterioration during the design life of the buried metallic casing. Application of additional coating breakdown factors are therefore not required.

27.8 Surface Area

Surface area of the buried metallic casing to be afforded cathodic protection shall be based on the total buried casing surface area.

27.9 Monitoring Facilities

27.9.1 Cable Connection to Casing

The cable connection to the buried casing shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to pipeline and structure.

Cable connections shall not be carried out on bends or within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All below grade cable connections shall be fully encapsulated to comply with the original coating standards. A holiday test shall be conducted before backfilling.

The following methods shall be used for cable connections:

Table 52 — Buried Casings - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Existing Pipeline Casings	N/A	Pin Brazing
New Pipeline Casings	N/A	Welded Pad

Notes.

(i) The cable shall be looped around the pipe to avoid damage to the connections by accidental pulling of the cable.

27.9.2 Monitoring Facility Types

At each road crossing buried metallic casing, a monitoring test post shall be installed on the downstream side. For road crossings having a width of more than 10m, two monitoring test posts, one at each side shall be provided.

Test facilities shall be above ground conduits with a terminal head/box on top.

The test facility shall contain a correctly sized shunt to monitor anode currents and a variable control resistor to control the anode current (to enhance anode life) and facilitate installation of new anodes in the future without touching the buried casing. It shall allow for monitor the pipe-to-soil potential of the carrier pipe as well as the casing pipe.

In addition, for metallic carrier pipes within the casing permanent reference electrodes shall be installed. These shall be encased in a geotextile sock and secured directly against the carrier pipe at the 6 o'clock position. The reference electrode shall be installed 2m from the casing end and the electrode cable tail routed to and terminated in the above ground test facility.

27.10 Interference

27.10.1 DC Interference

DC interference is not considered an issue for short buried sections of pipelines.

27.10.2 AC Interference

AC interference is not considered an issue for short buried sections of pipelines.

27.11 Electrical Isolation

Metallic casings provided at road or railway crossings to protect metallic carrier pipes shall be electrically isolated from each other.

Electrical isolation shall take the form of:

- Insulating (Link Seals or equivalent) installed on the carrier pipe, 150mm from each end of the casing, and
- Plastic (non-conductive) pipeline insulators, installed along the carrier pipe cased length to provide concentric support of the carrier pipe within the casing,

27.12 Anode Installation Procedure

All buried metallic casings at road crossings, shall be coated and protected with a CP system.

The sacrificial CP system shall be designed for a 20 year life (see sec. 27.3), with provision for replacement of anodes after 10 years.

Anodes shall be based on pre-packaged zinc or magnesium alloy type.

The type of the anode to be selected depends upon the environmental conditions and shall be selected as per the table below. These can be summarized as under:

Table 53 ─ Buried Casings - Sacrificial Anode as Function of Soil Resistivity

Sacrificial Anode	Soil Resistivity (Ohm.cm)
Zinc (Pre-packaged)	<1000
Magnesium (Pre-packaged)	>1000

Anode weight shall be calculated based on design current, design life, anode alloy capacity, efficiency and utilization factor. The anode tail cable shall be 1x10 mm^2 Cu/XLPE/PVC red cable.

Anodes shall be installed horizontally / vertically, alongside the buried casing, at / below invert depth and with a 1-2m separation. Anode cable tails shall be terminated within the test facilities provided.

The test facility shall be provided with a resistor and shunt to control and monitor anode current output.

A watering arrangement shall be provided to periodically water the anode (s).

The buried casing and carrier pipes routed through, shall be electrically isolated from each other using insulated spacers (PE spacers). The maximum separation between the spacers shall be 2m. End seals shall be provided to check the ingress of moisture and sand / soil. It shall be ensured that there is no electrical shorting between casing and carrier pipe.

For metallic carrier pipes, supplementary protection for the section of carrier pipe within the metallic casing shall be provided.

Zinc ribbon anode shall be used for the protection of carrier pipe where operating temperatures are lower than 55°C. Magnesium ribbon shall be used for higher temperatures.

The ribbon anode shall be installed in two lengths along the entire carrier pipe length, installed at the 5 and 7 o’clock positions on the carrier pipe. The ribbon anode shall be encased in a geotextile sock for its entire length and then secured against the carrier pipe at 1 metre intervals.

At the end of the ribbon anode, a cable shall be connected by hydraulic-crimped ferrule and encapsulated (to make water tight) to provide the anode cable tail. The cable shall be routed out of the end of the casing and terminated in the above ground test facilities installed at the end of the casing. For casings exceeding 10m length and provided with test facilities at each end, cable connection to each end of the ribbon anode shall be made and terminated in the appropriate test facility.

In addition non water absorbing foam material shall be injected from one entry nozzle to the casing to fill the whole annulus space.

27.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include calibration checks of permanent reference electrodes (if applicable).

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for connection of cathodic protection sacrificial anodes

(c) Procedure for testing and adjustment of casing-to-soil potential

(d) Requirements for polarization of the buried casing

(e) Procedures for full ON potential surveys

(f) Procedures for confirming electrical isolation testing between casing and carrier pipe

(g) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the buried casing

(h) Required format of the commissioning report

(i) Procedure for clearing the Punch List items

27.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the buried casing, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 54 .

Table 54 — Buried Casings - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years(ii)
Galvanic anode station	Visual check of the stations and measure the 'CP ON' casing-to-soil potential	One year
Galvanic anode station	Comprehensive functional tests of the galvanic station e.g. resistor setting, efficiency of the bonding connection and measurement of the 'CP ON' casing-to-soil potential	Three years

Notes.

(i) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years,

(ii) Measurements of the supplementary CP system applied to the carrier pipe will only be operational if the annulus between the carrier pipe and casing fills with water, activating the ribbon anode. In such an event the routine measurements as described in Table 54 shall be undertaken.

28 TECHNICAL REQUIREMENTS – OFFSHORE STRUCTURES

28.1 General

The CP design for offshore structures shall be based on a permanent sacrificial system designed in accordance with the requirements of DNVGL-RP-B401.

The offshore structures covers design criteria, parameters and calculations of cathodic protection sacrificial anodes used for platforms, jackets, piles, well conductors, wharves, J-tubes (including internal and external wetted surfaces) and floating units.

28.2 Design Documentation

The basis and detailed design documentation shall include, but not limited to:

- Conceptual design report.
- Relevant data of the structure design such as materials, dimensions, thickness, type of coating and design life.
- Relevant data of the marine environmental condition.
- Relevant documentation data such as anode manufacturing procedure and anode inspection test plan.
- Final detailed design calculations.
- Complete set of design drawings, including anode distribution, detailed anode design and construction drawings.
- Anode installation procedures.
- Pre-commissioning and commissioning procedures (if any).
- Operational manual

28.3 Cathodic Protection Criteria

The protection criteria to ensure adequate CP of the carbon steel structure shall be in accordance with the following values, with reference to a silver-silver chloride sea water reference electrode, and free of IR Drop:

- More negative than -800 mV Ag/AgCl-seawater in aerated seawater.
- For carbon steel with SMYS greater than or equal to 550 MPa, the potential shall remain more positive than -1100 mV Ag/AgCl-seawater.
- For other materials, potential requirements shall be in accordance with ISO 15589-2.

Note: In accordance with DNVGL-RP-B401, the use of a design protective potential of -900mVssc(sw) in an anaerobic environment, including typical seawater sediment, is not considered and -800mVssc(sw) shall be applied in all cases.

28.4 Design Life

The anode design life, t_f, to be considered in the calculation shall be minimum 40 years except unless the remaining operational life of the structure is specified.

For retrofitting of cathodic protection system of existing subsea structures, the design life shall be the same as the expected useful life of the structure to be protected.

28.5 Aluminum Zinc Indium Anode Parameters

The Aluminum-Zinc-Indium alloy shall have the following design parameters:

Table 55 — Offshore Structures - Aluminium Zinc Indium Anode Design Parameters

Al-Zn-In design parameters	Design Values
Close circuit anode potential at seawater	-1050 $mV_{ssc(sw)}$
Close circuit anode potential at sediments	-950 $mV_{ssc(sw)}$
Electrochemical capacity at seawater	≤30°C 2000 Amp-hr/kg
Electrochemical capacity at sediments	≤30°C 1500 Amp-hr/kg
Anode density	2700 kg/m^3

For aluminum anode electrochemical capacity with elevated temperature, alternative values may be used in reference to DNVGL RP F103 by interpolation method.

28.6 Design Resistivity

The resistivity of the electrolyte for anode sizing shall be as per the below table. Seawater resistivity shall be used if the anodes are free from the risk of sand blockade and sea mud resistivity shall be considered for buried or partially buried anodes. The below table shall be the conservative resistivity values to be used for anode sizing.

Table 56 — Offshore Structures - Conservative Design Resistivity of ADNOC Offshore

Electrolyte	Resistivity to be used in the design
Seawater (Non-buried)	15 Ω-cm
Sea mud (Anodes are buried or partially buried)	60 Ω-cm

28.7 Design Current Density

The number of anodes required for protection must satisfy three different calculations.

There must be enough anodes to polarize the structure initially (initial current density), to produce the appropriate current over the design life of the structure (mean current density), and to produce enough current to maintain protection at the end of the design life (final current density); the required current density values are indicated below:

Table 57 — Offshore Structures - Design Current Density in 'Tropical' (>20°C) Seawater Temperatures

Environment	Current Density, A/m2		
	Initial, $CDinitial$	Mean, $CDmean$	Final, $CDfinal$
0 — 30m depth	0.150	0.070	0.100
>30 — 100m depth	0.120	0.060	0.080
Buried Zone (mud zone)	0.020	0.020	0.020

For piping and other components heated by an internal fluid, the design current density specified in Table 5 shall be increased by 1 mA/m2 for each degree Celsius of the metal/environment interface above 25°C.

28.8 Coating Breakdown Factor

The coating breakdown factor calculated for initial, mean and final conditions shall be in accordance with the below table:

Table 58 — Offshore Structures - Coating Breakdown Factor for 40 Years Design Life

ZONE	Initial	Mean	Final
Splash	2%	26%	50%
Submerged	2%	26%	50%
Buried	100%	100%	100%

The recommended coating breakdown factor shall be calculated as per DNVGL RP B401 guidelines.

The above tabulated coating factor values are applicable only to new design but for existing structures that require CP refurbishment, the present coating breakdown factor (initial, mean and final) should be calculated taking into account the deterioration of the coating from the beginning of service of the structure

28.9 Anode Utilization Factor

The design utilization factor for CP calculation shall be based on the following anode types:

- Long slender stand-off (L≥ 4r) — 0.80
- Short slender stand-off (L< 4r) — 0.85
- Long flush mounted (L≥ 4.width & L≥ 4.thickness) — 0.85

28.10 Surface Area

The surface to be protected shall be divided into different zones (splash zone, submerged zone and buried zone). Calculations shall be carried out separately for each zone. The surface area in contact to seawater to be considered in the design calculation shall be from the mean sea level (MSL) up to the buried zone.

Calculations shall include any submerged or buried metallic surface in electrical continuity with the protected structure and considered as current consumers.

The definition of water depth zones shall be as per Design Basis of the Project Specification. Surface area calculation shall be made based on actual pile lengths for (i) drilled and grouted piles and (ii) driven piles and (iii) insert piles (coated or bare).

28.11 Anode resistance calculation for initial, mean and final condition

The final volume of the anode to be used for calculation can be calculated from the remaining net anode mass, specific density of anode material and the volume of insert material. The volume of the insert should be estimated to give a conservative approach.

28.12 Minimum number of anodes

The minimum anode net mass required to protect the structures shall be calculated using the current density at mean life coating condition, of different zone, as per the calculation below. However, the number of anodes required for protection must satisfy three conditions.

$$\mathrm{AW\ (Kg)} = \frac{\mathrm{I_{cp\ mean}} \times \mathrm{L} \times 8766}{\mathrm{C_{ec}} \times \mathrm{Ut}}$$

Where:

$\mathrm{AW} =$ minimum weight of anodes required, kg

$\mathrm{L} =$ CP Design life, years

$\mathrm{I_{cp}} =$ Current requirement of the structure, Amps

$\mathrm{C_{ec}} =$ Anode electrochemical capacity, $\frac{\mathrm{Amps-hr}}{\mathrm{kg}}$

$\mathrm{Ut} =$ Anode utilization factor

28.13 Conditions for Acceptance of the Offshore Structure Design

To validate the CP System design for offshore structures, following design verification shall be made

- Condition 1: Anode Quantity based on Current Requirement
  There must be enough anodes to polarize the structure initially (initial current density), where the summation of initial current output of all the anodes is greater than or equal to the total initial CP requirements.

- Condition 2: There must be enough anodes to produce the appropriate CP current over the design life of the structure (mean current density) where the summation of mean current output of all the anodes is greater than or equal to the total mean CP requirements
- Condition 3: There must be enough anodes to produce enough current to maintain protection at the end of the design life. This is to confirm that the summation of final current output of all the anodes is greater than or equal to the total final structure CP Requirements
- Condition 4: The total applied net anode weight should be more than the minimum anode net mass requirement

28.14 Installation of the Anode

Anodes shall be installed according to construction specifications, and anodes installation procedures shall be carried out according to the qualified Installation Procedure Specification (IPS) and Welding Procedure Specification (WPS), describing all the equipment and procedures to be used.

The stand-off anodes shall be installed only in the steel structures of the jackets, vertically, horizontally and/or diagonal members, in such a way that the distance between the center line of the anode's insert and the structure shall be 300 to 500 mm for all aluminum anodes.

Based on the theoretical number of anodes defined by the current requirement calculation of the different zones of the structure, practical distribution of the anodes shall take into consideration the following factors:

- Anodes shall be uniformly distributed on the structure.
- Anodes for the splash zone shall be located between the LAT and the first submerged level that is practicable.
- Anodes for the buried parts of the jacket including piles and underside of mud mats shall be located between the two lowest immersed levels.
- Anodes shall be located as symmetrically as possible on the structure, nearer complex and critical points such as node areas.
- Anodes protecting conductor pipes shall be uniformly distributed at the different levels in their immediate proximity on the conductor guide frames.
- Anodes corresponding to the current drain of wells shall be uniformly distributed over all the submerged part of the structure.
- For anodes retrofitting, sled anodes or anode tree arrangement can be used, and alternative methods for distribution and connection to the structure should be considered.

In general, offshore CP systems of ADNOC offshore fixed structures consist of distributed vertically and/or horizontally stand-off anodes mounted 300 mm to 500 mm offset from the structure members to ensure a uniform current distribution. Computer modeling can be used to verify proper current distribution.

28.15 Location of the Anode

The anodes shall be positioned on the surface they are designed to protect according to the following guidelines:

On legs, the anodes shall face the center of the structure.

On diagonals, the anodes shall be alternately placed on the upper and lower surface if more than one anode is required.

On horizontal bracings at different levels, the anodes shall be installed alternately facing up and down with the exception of the uppermost level where they shall be mounted facing downwards.

No anode shall be located above the LAT. The anodes for the splash zone below the MSL and below the mud zone shall be added to the number of anodes in the submerged zone. All the anodes shall be distributed in stable submerged zone below the LAT.

Anodes shall not be projecting out of the jacket external faces

28.16 Anode to Structure Electrical Connection

The electrical integrity between the anode and the structure is mainly provided by the anode insert and the attachment method to the structure, and low-resistance electrical contact must be maintained through the operating life of the anodes.

28.17 Electrical Isolation

Requirement for electrical isolation on offshore structures shall be considered on a case-by-case approach.

CONTRACTOR shall review the offshore structure scope and on consideration of any and all electrical isolation requirements advise COMPANY accordingly

28.18 Installation Acceptance Survey

A post installation survey should be carried out, after the CP polarization of the offshore structures to determine any areas of deficient protection, any areas of damage to the cathodic protection or monitoring system, and any items such as piles or clamps which require electrical continuity bonding to prevent accelerated corrosion.

This must be undertaken as soon as possible after placement of an offshore structure.

This baseline survey must be carried out within:

- 3 months for sacrificial anode systems, uncoated installations
- 12 months for sacrificial anode systems, coated installations

The baseline survey must extend to 100% of the structure and its cathodic protection systems.

It must include.

(a) 100% visual inspection of the cathodic protection system

(b) A representative steel/sea water potential survey of each vertical and each horizontal frame of the main structure

(c) A detailed potential survey of representative nodes on each vertical and each horizontal frame of the main structure.

(d) A detailed potential survey of known areas of high complexity and/or high surface density

(e) A detailed potential survey, specifically using local point contact for the measurement of areas of possible electrical discontinuity from the main structure.

28.19 Inspection of CP System Performance

A detailed CP survey based on risk assessment and the remote CP measurements taken at frequent intervals are part of the CP monitoring. The objective of the CP monitoring is to check that the cathodic protection system continues to perform satisfactorily and record where anodes have become depleted, damaged and detached. An indication of the depletion of anodes in volume percentage should be reported. CP readings should be taken around the primary structure, conductors, risers, clamps and secondary structures.

29 TECHNICAL REQUIREMENTS – OFFSHORE PIPELINES

29.1 General

Cathodic protection system shall be designed by Sacrificial bracelet type Aluminum –zinc-Indium (Al-Zn-In) anodes distributed at regular intervals along the pipeline to deliver the required current to maintain the protective potentials during the design life of the pipeline.

The anode design in general shall be in guidance with DNVGL-RP-F103 standard practice by taking Design Safety Factor 2.0. The other conservative design input parameters as stipulated here from ISO 15589-2 and DNVGL-RP-B401 shall also be considered.

The basic and detailed design for Cathodic Protection of submarine pipelines will include:

(a) Description of the basis of the design project specification, codes, and standards.

(b) Basic design report.

(c) Relevant data of pipeline design: pipeline materials, dimensions, thickness, fluid temperature, type of coating, design life, marine environmental conditions.

(d) Relevant data of marine environment: environmental conditions, current speed degree of burial, pipeline route.

(e) Relevant data for anode manufacturing and testing.

(f) Final design calculations: based on accurate Manufacturer's information: anode weight, dimensions and performance data.

(g) A complete set of design drawings, including anode distribution, detailed anode design and construction.

(h) Pre-commissioning and commissioning procedures

(i) Installation procedures.

(j) Calculations of surface area, current requirement, selection of anode material, tentative net mass and dimensions of anodes, numbers of anodes and anodes attachments.

Detailed design conditions and calculations will determine the size and number of anodes to be installed; then, with the length of the pipeline the spacing between anodes shall be determined to maintain the adequate protection demonstrated by potential attenuation calculations.

Pipeline bracelet anodes that are flush mounted with a concrete coating, the thickness of the concrete coating layer shall be taken into account when determining the overall dimensions of the anode installation.

Short pipelines less than 1000 metre length may be protected by sled anodes connected to both ends of the pipeline, provided that the attenuation calculations demonstrate cathodic protection coverage of the whole length of the pipeline.

If electrical isolation joint for the subsea pipeline is applied in the onshore to offshore transition where onshore structures are protected with impressed current CP systems, it is required to apply a suitably rated surge arrestor to the isolation joint. Application of minimum 2 Nos. prepackaged zinc anode with minimum net anode weight of 35 kg is required complete with test station, coupon, and access hole. Test stations shall be accessible and outside the fence of the valve pit.

Electrical isolation between subsea pipelines and topside piping in wellhead towers and super complex, with compatible sacrificial anodes, is not recommended. Experience indicates that electrical isolation is ineffective in the long term in the offshore environment and susceptible to failures and leaks.

29.2 Cathodic Protection Criteria

The protection criteria to ensure adequate CP of the carbon steel structure shall be in accordance with the following values, with reference to a silver-silver chloride sea water reference electrode, and free of IR Drop:

(a) More negative than -800 mV Ag/AgCl-seawater in aerated seawater.

(b) More negative than -900 mV Ag-AgCl-seawater in a seawater environment with a potential high content of sulphate reducing bacteria and for part of the subsea pipeline buried in sediments.

(c) For carbon steel with SMYS greater than or equal to 550 MPa, the potential shall emain more positive than -1100 mV Ag/AgCl-seawater.

(d) For other materials, potential requirements shall be in accordance with ISO 15589-2.

29.3 Design Life

The anode design life, t_f, to be considered in the calculation shall be minimum 40 years except unless the remaining operational life of the structure is specified.

For retrofitting of cathodic protection system of existing subsea pipelines, the design life shall be the same as the expected useful life of the structure to be protected.

29.4 Design Factor

The design factor of minimum 2.0 shall be included in the calculation of initial, mean and final current requirement.

Special design allowance shall be applied for segments of subsea pipelines approaching artificial islands with onshore well casings protected by ICCP system. This is applicable to segments 500 m from the artificial islands. The design allowance in such cases shall be 3.0 and additional 3 bracelet anodes on the stable submerged part of the pipeline shall be considered in the design.

29.5 Aluminum Zinc Indium Anode Parameters

The Aluminum-Zinc-Indium alloy shall have the following design parameters:

Table 59 — Offshore Pipelines - Aluminium Zin Indium Anode Design Parameters

Al-Zn-In design parameters	Design Values
Close circuit anode potential at seawater	-1050 $mV_{ssc(sw)}$
Close circuit anode potential at sediments	-1000 $mV_{ssc(sw)}$
Electrochemical capacity at seawater	≤30°C 2000 Amp-hr/kg
Anode density	2700 kg/m^3

For aluminum anode electrochemical capacity with elevated temperature, alternative values may be used in reference to DNVGL RP F103 by interpolation method.

Table 60 — Offshore Pipelines - Excerpt from Table 6-3 of DNVGL-RP-F103

Anode material	Anode Surface Temperature (°C)	Seawater exposure		Sediment exposure	
		Closed Circuit potential (V)	Electrochemical capacity (A-hr/kg)	Closed Circuit potential (V)	Electrochemical capacity (A-hr/kg)
Al-Zn-In	≤ 30	-1.050	2000	-1.000	1500
	60	-1.050	1500	-1.000	680
	80	-1.000	720	-1.000	320

Pipelines operating with hot products generating temperatures above 30°C on the outside surface of the pipe shall require an adjustment to the design of pipeline current density and anode electrochemical capacity.

29.6 Design Resistivity

The resistivity of the electrolyte for anode sizing shall be as per the below table. Seawater resistivity shall be used if the anodes are free from the risk of sand blockade and sea mud resistivity shall be considered for buried or partially buried anodes. The below table shall be the conservative resistivity values to be used for anode sizing.

Table 61 — Offshore Pipelines - Conservative Design Resistivity of ADNOC Offshore

Electrolyte	Resistivity to be used in the design
Seawater (Non-buried)	15 Ω-cm
Sea mud (Anodes are buried or partially buried)	60 Ω-cm

29.7 Current Density

The number of anodes required for protection must satisfy three different calculations.

There must be enough anodes to polarize the structure initially (initial current density), to produce the appropriate current over the design life of the structure (mean current density), and to produce enough current to maintain protection at the end of the design life (final current density); the required current density values are indicated below:

Table 62 — Offshore Pipelines - Design Current Density at 30°C Seawater Temperature

Environment	Current Density, A/m2		
	Initial, $CDinitial$	Mean, $CDmean$	Final, $CDfinal$
Splash Zone below MSL (Risers)	0.160	0.080	0.100
Submerged Zone	0.150	0.070	0.100
Buried Zone (mud zone)	0.025	0.025	0.025

The design of cathodic protection for submarine pipelines shall consider that current would drain to subsea components i.e. fixed offshore structures, mud mats, subsea wells, skirts and pilings below the mud zone. All these structures must be electrically continuous and ensure that the CP current drains for these offshore structures are covered in the design calculation. Additional 1 anode shall be applied on the part of the pipeline approaching the fixed offshore structures at each end of the pipeline to compensate the drains.

For elevated pipeline surface temperatures, the current density shall be increased by 1 mA/m2 for each degree Celsius of the metal/environment interface above 30°C.

29.8 Coating Breakdown Factor

The coating breakdown factor calculated for initial, mean and final conditions shall be in accordance with the below table:

Table 63 – Offshore Pipelines - Coating Factor for ADNOC Offshore Subsea Pipelines with Field Joint Infill in line with ISO 15589-2

Factory Applied Coating	Field Joint Coating Type	$k1$	$k2$
3LPE / 3LPP with CWC	HSS, FBE or Multilayer coating	0.004	0.0002
Thick elastomeric materials or glassfiber-reinforced resin (Typical for risers)	Thick elastomeric materials or glassfiber-reinforced resin	0.002	0.0001

For other coating types, the coating factor shall be referred to ISO 15589-2 table 3 and table 4.

The recommended coating breakdown factor shall be calculated as per DNVGL RP B401 guidelines.

For existing structures that require CP retrofitting, the present coating breakdown factors (initial, mean and final) should be calculated taking into account the deterioration of the coating from the beginning of service of the structure.

29.9 Anode Utilization Factor

The design utilization factor for CP calculation shall be based on the following anode types:

- Bracelet anodes (min. thickness 50mm) – 0.80
- Elongated stand-off type – 0.85
  (anodes placed on other subsea structures for protection of the pipeline)

29.10 Surface Area

The pipeline shall be divided into segments depending on the change of pipeline coating, the thickness of concrete weight coating, size of the pipeline, etc. Each segment shall be tabulated separately complete with pipeline details. The total surface area shall be calculated separately for each pipeline segment. The bare surface area shall be calculated using the initial, mean and final coating breakdown factor as per subsection 29.8 table 63 above.

29.11 Anode to Anode Spacing

The maximum anode to anode spacing shall be limited to 200m. However, attenuation calculation shall be performed for anode spacing more than 100m.

29.12 Anode Requirement based on Mass Calculation

The minimum anode mass required in each segment shall be calculated based on Mean current requirement.

29.13 Anode Requirement based on Current Calculation

The single anode current output shall be calculated based on single anode resistance, driving voltage and the initial, mean and final anode condition.

29.14 Conditions for Acceptance of the Design

To validate the CP System design, following design verification shall be made

- Condition 1: Anode Quantity based on Current Requirement
  There must be enough anodes to polarize the structure initially (initial current density), to produce the appropriate CP current over the design life of the structure (mean current density) and to produce enough current to maintain protection at the end of the design life
- Condition 2: Total Net Anode Weight
  The total applied net anode weight should be more than the minimum anode net mass requirement
- Condition 3: Anode Spacing
  The maximum anode to anode spacing shall be limited to 200 m justified by attenuation calculation
- Condition 4: Crack Propensity Ratio (CPR)
  The anode dimensions are limited to a certain length to thickness ratio to prevent the risk of anode cracking. The CPR calculation shall be made to ensure the anode dimension is suitable and to achieve the CPR ratio criteria less than 3.
- Condition 5: Additional Anodes
  Additional 1 anode shall be applied on the part of the pipeline approaching the fixed offshore structures at each end of the pipeline to compensate the drains.
  Additional 3 anodes shall be added on the part of the pipeline approaching artificial islands with ICCP system with or without isolation joints.
  Any additional requirement that is necessary to achieve complete protection of the pipeline should be considered even not specifically mentioned in this specification.
- Condition 6: Subsea Pipeline Crossing
  For subsea pipeline crossings, one additional bracelet anode, designed suitable for the pipe section, shall be provided immediately outside each touchdown points.

29.15 Anode Installation Procedures

The requirements and guidelines of this section are in accordance with ISO 15589-2 Section 11. Installation of bracelet type galvanic anodes on submarine pipelines shall be described in detail in the Installation Procedure Specification (IPS), in addition to the following:

- Anodes to be mounted on pipelines without concrete weight coating shall be designed with a tapered shape or to be provided with tapered end fittings as required for the pipeline laying process.
- Anodes shall not be installed on the risers. Cathodic protection of the risers should be provided from the adjacent pipeline or by retrofitting anodes to the platform where the riser is located.
- The location of anodes in relation to pipe ends or field joints shall be submitted to COMPANY for approval before any installation of line pipe will start.
- The anode shall be placed so that the location of the subsequent cable attachment to the pipe is 200 mm minimum from the longitudinal or vertical weld seam
- Precaution shall be made to prevent any electrical connection/drain between the anode and concrete coating metallic reinforcements
- Anode Cable Connection to the pipeline will be through two plastic braided-copper pigtails per half shell which will be connected to the pipeline in the slots between the shells. There shall be minimum

four (4) armored bonding cables with seven strands, No. 6 AWG (16 mm2), which shall be used to connect the insert of the anodes to the subsea pipeline.

- Each cable connections shall be single core galvanized steel wire armored (GSWA) cable equivalent to CU/XLPE/PVC/GSWA.
- Electrical connection between the copper wire and the steel insert shall be performed by thermite welding
- The electrical continuity between anode and the pipeline shall be checked after the connection. The measured resistance between the anode and the pipeline shall be less than 0.1 Ω
- Anode Gaps after the installation of the bracelet anode, typically 30 mm, on each side of the anode, shall be filled in by HDPUF infill material to the same diameter of the concrete coating. The same concrete mix may be used as a filler material between the anode and the concrete coating subject to COMPANY approval.

29.16 Electrical Isolation

Electrical isolation in the form of isolating joints/flanges shall be applied at the interface where the offshore pipeline comes onshore.

The installation of electrical isolation will:

(i) Isolate the offshore CP system (normally sacrificial - Aluminium alloy anodes) from the CP system for the onshore pipeline (normally ICCP or sacrificial based on magnesium alloy anodes),

(ii) Isolate the offshore CP system from the effects of onshore earthing systems

Where the internal product contains a water layer which could lead to internal corrosion at the electrical isolation point, requirement for internally coated isolation joints or installation of an isolating spool piece shall be considered.

The CONTRACTOR shall investigate the options for internally coated lined isolation joints or isolating spools and submit with his basic design the chosen option with any and all considered evidence for COMPANY review/approval.

29.17 Post Pipeline Installation Survey

A post pipeline installation survey should be carried out, after the CP polarization of the subsea pipeline, which is typically between 6 to 12 months after pipeline installation. The new cathodic protection system of subsea pipelines shall be validated by ROV as-built survey.

The subsea pipeline cathodic protection system survey using remotely operated vehicle (ROV) shall be equipped to perform twin half-cell contact probe with remote reference in full compliance with ISO 15589-2:2012 Annexure D, CP Monitoring, and Surveys.

29.18 In-depth Cathodic Protection Inspection Survey

The recommended frequency of in-depth CP inspection which includes General Visual Inspection (GVI) and CP measurements shall be 5 years between surveys with risk assessment performed during surveys to determine the recommended interval required. The in-depth cathodic protection survey shall be conducted as per the minimum inspection requirement in sub-section 29.17.

29.19 ICCP System Interference

The subsea pipelines are protected with sacrificial anodes that are typically amphoteric metals. It is recommended to isolate the subsea pipelines to the onshore pipeline to separate different type of CP system. This is to avoid premature failure of the sacrificial anodes and prevent diversified interference on the offshore structures and subsea pipeline network.

30 TECHNICAL REQUIREMENTS – JETTIES / SEA WATER INTAKES

30.1 General

The CP design for jetties/seawater intakes shall be based on a permanent ICCP system designed in accordance with the requirements of DNVGL-RP-B401 and ISO 15589-2.

This section covers design criteria, parameters and calculations of cathodic protection systems used for jetties and seawater intakes.

30.2 CP Criteria

The protection criteria to ensure adequate CP of the jetties / sea water intakes structure shall be in accordance with the following values, with reference to a silver-silver chloride sea water reference electrode, and free of IR Drop:

- More negative than -800 mV Ag/AgCl-seawater in aerated seawater.
- For carbon steel with SMYS greater than or equal to 550 MPa, the potential shall remain more positive than -1100 mV Ag/AgCl-seawater.
- For other materials, potential requirements shall be in accordance with ISO 15589-2.

Note: In accordance with DNVGL-RP-B401, the use of a design protective potential of -900mVssc(sw) in an anaerobic environment, including typical sea water sediment, is not considered and -800mVssc(sw) shall be applied in all cases

30.3 Design Life

The anode design life, to be considered in the calculation shall be minimum 30 years except unless the remaining operational life of the structure is specified.

For retrofitting of cathodic protection system of existing subsea structures, the design life shall be the same as the expected useful life of the structure to be protected.

30.4 Anode/Groundbed Parameters

30.4.1 Anodes

Anodes for use in the protection of jetties and sea water intakes shall be as follows:

- Mixed metal oxide (MMO) coated titanium tubes or rods
- Platinum coated niobium or titanium rods

The MMO anode shall have the following design parameters:

Table 64 — Jetties/Sea Water Intakes - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Tubular Anode	Design Values
Tubular anode size (min)	25mm dia. X 1000mm long
Titanium (tubular)	ASTM B338, grade 1
Current density (in sea water)	Max. 600 A/m^2
MMO/Titanium parameters - Rod Anode	**Design Values**
Rod anode size (min)	12.7mm diameter x 230mm length
Titanium (rod)	ASTM B348, grade 1
Current density (in sea water)	Max. 600 A/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly

The Platinum anode shall have the following design parameters:

Table 65 — Jetties/Sea Water Intakes - Platinum Anode Design Parameters

Pt/Ti or Pt/Nb parameters	Design Values
Rod anode size (min)	12.7mm diameter x 230mm length
Titanium (rod)	ASTM B348, grade 1
Current density (in seawater)	Max. 1000 A/m^2

30.4.2 Groundbeds

Protection of jetty piles and the steel structures within the sea water intakes shall be protected by a distributed anode CP system.

For jetty piles, anodes shall be installed vertically in the sea water attached on stand-off brackets to a pile or suspended between pilings to provide protection to multiple piles.

Sea water intakes shall be divided into zones based on; stop logs, racking bar screen, travelling band screen and pump bays and downstream of the pump inlet stop logs.

Anode groundbeds located in sea water shall be designed to have a resistance to remote earth less than 1.0 ohm and fulfil anode current output characteristics under normal electrolyte conditions.

Maximum voltage between anode material and electrolyte (in sea water environments) are given in EN 13174 as 8V. However, it should be noted that this is applicable for exposed titanium and that fully platinised or MMO coated titanium will be capable of supporting much higher voltages.

NACE Corrosion Paper 2107, indicates that fully coated titanium based anodes will be capable of operating upto 50-60V without signs of 'breaking potential' being reached.

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system
- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- The risk of causing harmful interference on other structures is minimized
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

30.5 Design Resistivity

The resistivity of the electrolyte for anode/CP system sizing shall be as per the below table. Sea water resistivity shall be used if the anodes are free from the risk of sand blockade and sea mud resistivity shall be considered for buried or partially buried anodes. The below table shall be the conservative resistivity values to be used for anode sizing.

Table 66 — Jetties/Sea Water Intakes - Conservative Design Resistivity of ADNOC Offshore

Electrolyte	Design Resistivity Values
Sea water (Non-buried)	15 Ω-cm
Sea mud (Anodes are buried or partially buried)	60 Ω-cm

30.6 Current Density

The CP design for jetties and sea water intake structures shall be based on an ICCP system designed in accordance with the requirements of DNVGL-RP-B401.

The CONTRACTOR shall carry out ICCP system calculations to determine current requirements to meet the final design currents.

The current densities to be applied in the CP design shall be as detailed in Table 67 .

Table 67 — Jetties/Sea Water Intakes - Current Densities for Seawater Exposed Bare Metal Surfaces

Depth (m)	Current density for bare steel in Tropical (> 20°C) environment (A/m²)		
	Initial	mean	final
0-30	0.150	0.070	0.100
>30-100	0.120	0.060	0.080
Buried (sediment)	0.020	0.020	0.020

Notes.

(i) Average sea water temperatures for the UAE waters is based on 27°C.

(ii) Current density values based on DNVGL-RP-B401 Table A-1 and A-2.

For freely flooded compartments and for closed compartments with free access to air e.g. seawater intakes and/or screens, design current densities for 30-100m given in Table 67 are recommended

30.7 Coating Breakdown Factor

The coating breakdown factors to be applied in the CP design shall be as detailed in Table 68.

Table 68 — Jetties/Sea Water Intakes - Recommended Constants (a and b) for Calculation of Coating Breakdown Factors

Depth (m)	Recommended a and b values for Coating categories I, II and III		
	I (a = 0.10)	II (a = 0.05)	III (a = 0.02)
0-30	b = 0.10	b = 0.025	b = 0.012
>30	b = 0.05	b = 0.015	b = 0.008

Notes.

(i) Coating breakdown constants based on DNVGL-RP-B401 Table A-4.

(ii) Coating categories (based on DNVGL-RP-B401 sec. 6.4.6) are defined as:

1. Category I - one layer of epoxy paint coating, min. 20µm nominal DFT

2. Category II - One or more layers of marine paint coating (epoxy, polyurethane or vinyl based), total nominal DFT min. 250µm

3. Category III - Two or more layers of marine paint coating (epoxy, polyurethane or vinyl based), total nominal DFT min. 350µm

(iii) For structures buried in sediment (jetty piles/legs) coating break down factor shall be considered as 100% (bare steel)

30.8 Surface Area

The surface to be protected shall be divided into different zones (splash zone, submerged zone and buried zone). Calculations shall be carried out separately for each zone. The surface area in contact to seawater to be considered in the design calculation shall be from the mean sea level (MSL) up to the buried zone.

Calculations shall include any submerged or buried metallic surface in electrical continuity with the protected structure and considered as current consumers.

The definition of water depth zones shall be as per Design Basis of the Project Specification.

30.9 Monitoring Facilities

30.9.1 Cable Connection to Jetties/Sea Water Intakes

The cable connection to the jetty or sea water intake shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the structure.

Cable connections shall not be carried out within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All submerged cable connections shall be fully encapsulated to comply with the original coating standards.

The following methods shall be used for cable connections:

Table 69 — Jetties/Sea Water Intakes - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Jetties / Sea water Intakes	Welded Pad	Welded Pad

30.9.2 Monitoring Facility Types

Permanent reference electrodes shall be used for monitoring the CP system applied to jetties or sea water intakes and shall be installed in the same manner as for the anodes (see sec. 30.12).

The location of the reference electrodes is very important, particularly when used to control the system. Permanent reference electrode shall be installed at locations where the potential of the structure may become outside the protection criteria.

For sea water intakes, a minimum of two (2) no. permanent reference electrodes shall be provided per zone for monitoring.

Reference electrodes shall be based on silver/silver chloride (Ag/AgCl) type, individually cabled. The electrode cable tails shall be routed back to a monitoring test facility, either individually for each electrode or as a single test box with all electrode cable terminations.

30.10 Interference

30.10.1 DC Interference

DC interference is not considered an issue for jetties / sea water intakes.

30.10.2 AC Interference

AC interference is not considered an issue for jetties / sea water intakes.

30.11 Electrical Isolation

Requirement for electrical isolation on jetties and sea water intakes shall be considered on a case-by-case approach.

CONTRACTOR shall review the jetty / sea water intake scope and on consideration of any and all electrical isolation requirement advise COMPANY accordingly.

Consideration shall be given for marine jetties to ensure electrical isolation of the jetty loading arms, pumps, slop vessels and any other steel structure from the steel piles and concrete steel rebar.

For sea water intakes electrical isolation from any foreign metallic components shall be undertaken.

Note.

Electrical continuity between the cathode circuits shall be ensured to enable effective application of the CP system. This shall include the steel piles supporting the marine jetty or seawater screen equipment within the sea water intake.

30.12 Anode Installation Procedure

Protection of jetty piles and the steel structures within the sea water intakes shall be protected by a distributed anode CP system.

ICCP anodes shall be of the tubular or rod type and supplied each with individual cable tails, which shall be terminated in anode junction boxes with current measurement and control facilities.

For jetty piles, anodes shall be installed vertically in the sea water attached on stand-off brackets to a pile or suspended between pilings to provide protection to multiple piles. Suspended anodes shall be properly secured to avoid damage due to waves.

For anodes connected to individual jetty piles, additional coating thickness shall be applied to the pile opposite the anode to provide a dielectric shield to protect from high negative potentials generated directly opposite the anode.

Jetty piles shall be bonded together to ensure the structure is electrically continuous and acts as a single cathode.

Sea water intakes shall be divided into zones based on; stop logs, racking bar screen, travelling band screen and pump bays and downstream of the pump inlet stop logs.

Current demand calculations shall be carried out for each part of the zones to ensure complete protection of all metallic surfaces of the equipment exposed to sea water within each part.

Adequate electrical continuity shall be provided in the design. Foreign metallic components shall be isolated from the protected structure.

ICCP anodes shall be located adequately to provide uniform current distribution on both sides of the structures, avoiding screening effects of other parts of the installation.

Permanent reference electrodes shall be used for monitoring and shall be installed in the same manner as for the anodes. The location of the reference electrodes is very important, particularly when used to control the system. Permanent reference electrode shall be installed at locations where the potential of the structure may become outside the protection criteria.

For sea water intakes, a minimum of two (2) no. permanent reference electrodes shall be provided per zone for monitoring.

30.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include calibration checks of permanent reference electrodes, electrical isolation checks, continuity bonds checks.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for energizing cathodic protection hardware

(c) Procedure for testing and adjustment of structure-to-sea water potential

(d) Requirements for polarization of the structure

(e) Procedures for full ON / OFF potential surveys

(f) Procedures for electrical isolation testing

(g) Procedures for continuity bonds testing

(h) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the structure

(i) Required format of the commissioning report

(j) Procedure for clearing the Punch List items

30.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the pipeline, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 70.

Table 70 — Jetties / Sea Water Intakes - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, measurement of the earthing system,	One to three years

	control of instruments, and measuring of the output voltage and current	
Permanent reference electrode (PRE)	Comparison with a reference electrode whose accuracy can be traced to a master electrode	One to six years(ii)
Selected test stations	Measurement of 'CP ON' potential	One year
All test stations	Measurement of 'CP OFF' / polarised potential (i)	Three years

Notes.

(i) The performance and the repeatability of the permanent reference electrode depends upon the type of reference electrode and the frequency of measurements. The periodicity, therefore, can vary between one and six years

31 TECHNICAL REQUIREMENTS – REINFORCED CONCRETE

31.1 General

The CP design for reinforced concrete shall be based on a ribbon mesh with titanium conductor bars embedded in the concrete in independently controlled zones over the reinforcing steel.

This section covers design criteria, parameters and calculations of cathodic protection systems used for various types of reinforced concrete structures including foundations, piles, pile caps, jetty areas, sheet piles.

31.2 CP Criteria

The protection criteria to ensure adequate CP of reinforced concrete structures shall be in accordance with any one the following three criteria:

- An instant off potential (measured between 0.1 s and 1 s after switching the dc circuit off) more negative than -720 mV with respect to Ag/AgCl/0.5M KCl.
- A potential decay of at least 100 mV from instant off over a maximum period of 24 hours.
- A potential decay over an extended period (typically 48 hour or longer up to maximum of 96 hour) of at least 150 mV from the instant off subject to continuing decay (using only embeddable reference electrodes at representative locations)

In meeting any of the above criteria, instant off steel potential of the protected structure shall not be permitted to be more negative than -1100 mV with respect to Ag/AgCl/0.5M KCl for reinforcing steel or -900 mV Ag/AgCl/0.5M KCl for pre-stressing steel.

31.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for reinforced concrete CP systems, shall be as follows:

- Permanent ICCP system – 50 years,

31.4 Anode/Groundbed Parameters

31.4.1 Anodes

Anodes for use in the protection of reinforced concrete shall be as follows:

- Mixed metal oxide (MMO) coated titanium ribbon mesh

The MMO/Ti anode shall have the following design parameters:

Table 71 — Reinforced Concrete - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Ribbon Anode	Design Values
Ribbon mesh anode size (min)	10mm width
Titanium	ASTM B265, grade 1
Current density (in concrete)	Max. 110 mA/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 75 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly

31.4.2 Groundbeds

The installation of the CP system and extent of cathodic protection of reinforcing steel in different types of structures shall be as follows

Table 72 — Reinforced Concrete - Extent of Cathodic Protection

Structures	Extent of Protection
Seawater Structures: Intake & discharge ponds and/or basins, cooling towers including wind wall , pump sumps, canals, basins and sumps etc. Note: Any pipe rack foundations/ pipe sleepers exposed to sea water sprays and/or overflows included.	The CP system shall be designed and installed to protect all reinforcing steel within the entire protected structure, i.e. from bottom slab to full height including all parts, sections or elements that are buried, submerged and atmospherically exposed internal and external concrete surfaces.
Critical process water, waste water or liquid containing structures: Ponds, basins & cooling towers, and slurry ponds & clarifier tanks etc.	The CP system shall be designed and installed to protect all reinforcing steel in all: • Buried areas and up to 0.5m above grade level. • Submerged areas up to maximum water level. • Tidal or splash zone areas, i.e. up to 1m above the maximum water level.
Critical Equipment Foundations: Reactor, compressor, turbine, & boiler foundations etc.	The CP system shall be designed and installed to protect all reinforcing steel in all buried areas and up to 0.5m above grade level.

31.5 Design Resistivity

Design resistivity values shall be based on the concrete resistivity measurements recorded during pre-design site surveys.

31.6 Current Density

CP system shall be capable of delivering sufficient protective current to polarize the structure satisfactorily so that selected criterion for CP is attained efficiently.

The CONTRACTOR shall carry out calculations to determine the anode zone sizing to ensure uniform current distribution and control to the reinforcing steel.

The current densities to be applied in the CP design shall be as detailed in Table 73.

Table 73 — Reinforced Concrete - Design Current Densities

Steel Embedded in Concrete	Current density for bare steel (mA/m²)
All new structures and foundations	not be less than 5 mA/m^2 of steel surface area
All existing, old and deteriorating structures and foundations	not be less than 20 mA/m^2 of steel surface area
For submerged areas only	between 10 to15 mA/m^2 of steel surface area

Notes.

(i) The contractor shall obtain CCPD/PMT approval for applying design current density between 10 to15 mA/m2 of steel surface area.

(ii) Maximum allowable current density at the anode-concrete interface shall be 110 mA/m2 of anode surface.

31.7 Coating Breakdown Factor

The coating breakdown factor to be applied in the CP design shall be as detailed in Table 74.

Table 74 — Reinforced Concrete - Coating Breakdown Factor for Reinforced Concrete Steel

Steel Embedded in Concrete	Coating breakdown factor for 'final' design
All existing and new structures in all environments	100%

Notes.

(i) All steel reinforcing embedded in concrete is 'bare' not coated.

(ii) Reinforcing steel shall not be connected to the earthing system. Since CP protected foundations reinforcements are not connected to earthing, the safety grounding requirement for rebar shall be verified during detailed engineering by CP vendor.

(iii) All critical concrete foundation re-bars shall be protected by dedicated cathodic protection using internal embedded anodes. All other structure concrete foundation shall be coated (external surface of foundation) and / or isolated polythene membranes to reduce current drain.

(iv) Metal-to-metal contact shall be avoided between reinforcing steel in concrete and the drum screens, stop log guides and bar screens.

31.8 Surface Area

Surface area of the reinforced steel in concrete to be afforded cathodic protection shall be based on the total steel surface area.

In calculating steel surface area, minimum of 15% allowance shall be added to the calculated steel surface area to cover steel bar overlapping and other items such steel chairs, links etc.

31.9 Monitoring Facilities

Permanent reference electrodes based on silver/silver chloride (Ag/AgCl) or manganese dioxide (MnO_2), shall be installed in each anode zone for potential monitoring. A minimum of 2no. reference electrodes and 2no. pseudo electrodes shall be provided for each anode zone. Where an anode zone consists of sub-anode zones, then 1no. reference electrode and 1no. pseudo electrode shall be provided in every sub-anode zone upto $100m^2$.

Reference electrodes shall be positioned such that they represent the most exacting geometric configuration for each zone or sub-zone i.e. diametric opposition.

Reference electrode cable tails shall be colour coded and routed to and terminated within monitoring test boxes.

Remote monitoring and control system shall be provided for the reinforced steel in concrete ICCP system.

31.10 Interference

31.10.1 DC Interference

DC interference is not considered an issue for reinforced concrete.

31.10.2 AC Interference

AC interference is not considered an issue for reinforced concrete.

31.11 Electrical Isolation

CONTRACTOR shall review the reinforced concrete scope and on consideration of any and all electrical isolation requirements advise COMPANY accordingly

31.12 Anode Installation Procedure

MMO ribbon mesh anodes shall be used for the protection of steel reinforcing on concrete.

The anode circuit is the principle basis of zoning a cathodic protection system in concrete embedded anode system. A zone is a discrete section of concrete structure powered by an independently controlled output from a dc power supply. Within any zone there may be a requirement to combine several different areas of structure that experience the same exposure condition, called sub-zones, e.g. columns or beams or sections of slab either side of expansion joints. However each sub-zone will require its own positive and negative connections and separate monitoring according to the constraints of the design. These combinations of sub-zones shall also be restricted to those areas which experience similar conditions of rebar density and concrete quality.

Anodes shall be installed in discrete zones and powered by individual transformer rectifiers to enable uniform current distribution to the reinforcing steel and to have better control over current adjustment in different parts of the structure.

To ensure the successful operation of the CP system, the embedded and surface mounted steel work shall be a homogeneous cathode. To be assured of this, a continuity survey shall be performed between the reinforcement cage and all externally mounted or embedded steelwork and between different sections of the reinforcement cage.

The structure to be protected shall be divided into zones as per the various exposure conditions; submerged, atmospheric exposed, buried or humid. Within each zone anode zones shall be installed based on current calculations and current spread requirements for the reinforcing steel. Anode zone sizes may vary within a structure, typically between 200 and 500m^2 of concrete surface area or more for very large structures. In any case anode zone sizes shall not exceed 750m^2 of concrete surface area.

Anode to anode spacing shall not exceed 300mm.

Anode zones may be divided into sub zones as required. Titanium conductor bars shall be used to join different anode sections as required. The connection between conductor bars and anodes shall be by resistance welding.

A minimum of two (2) nos. positive and two (2) nos. negative connections shall be made to each anode zone or sub zone. The positive connections shall be spot welded to the conductor bar using a titanium rod connected to an insulated anode cable.

Mesh anodes shall be securely attached to the reinforcing steel using non-metallic clips, so that during construction activities such as concrete pouring, the anodes do not move and make electrical contact with the steel reinforcing.

Permanent reference electrodes based on silver/silver chloride (Ag/AgCl) or manganese dioxide (MnO_2), shall be installed in each anode zone for potential monitoring. A minimum of 2no. reference electrodes and 2no. pseudo electrodes shall be provided for each anode zone. Where an anode zone consists of sub-anode zones, then 1no. reference electrode and 1no. pseudo electrode shall be provided in every sibsub-anode zone up to 100m^2.

Reference electrodes shall be positioned such that they represent the most exacting geometric configuration for each zone or sub-zone i.e. diametric opposition.

Voltage drop between the power supply terminals and the furthest point in the circuit of any anode zone typically shall be less than 300mV.

31.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include continuity survey between the reinforcement cage and all externally mounted or embedded steelwork and between different sections of the reinforcement cage, calibration checks of permanent reference electrodes.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for natural potential surveys

(b) Procedures for energizing cathodic protection hardware

(c) Procedure for testing and adjustment of steel reinforcing-to-concrete potential

(d) Requirements for polarization of the steel reinforcing

(e) Procedures for full ON / OFF potential surveys

(f) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the reinforced concrete

(g) Required format of the commissioning report

(h) Procedure for clearing the Punch List items

31.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the reinforced steel concrete structure, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with Table 75.

Table 75 — Reinforced Concrete - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, control of the PRE, resistance determination of the groundbed, measurement of the earthing system, control of instruments, and measuring of the output voltage and current	One to three years
Concrete corrosion monitoring system	Measurement of ‘CP ON’ and ‘CP OFF’ / polarised potential	One month (for the first 12 months)
Concrete corrosion monitoring system	Measurement of ‘CP OFF’ / polarised potential [(i)]	Three month (after first 12 months)

32 TECHNICAL REQUIREMENTS – WELL CASINGS

32.1 General

The CP design for well casings shall be based on a permanent impressed current system.

The section well casings covers design criteria, parameters and calculations of cathodic protection systems used for well casings located onshore and offshore (on artificial islands).

32.2 CP Criteria

Cathodic protection of well casings, either as a single well, or multiple wells in a cluster shall be based on achieving a net flow of current to each of the wells and NOT on the well casing to soil potential.

The CP current applied to the well casing shall be considered adequate when measurements indicate that a net flow of current to the casing has eliminated all anodic areas.

CPET or CPP corrosion logs are the only techniques capable of identifying unprotected areas along the well casing. Running a CPET or a corrosion log is often delayed for one reason or other on operational ground. The CPET / CPP therefore shall be planned in close coordination with Drilling team / Integrity Division team during the interim period of well casing construction. CPET tool shall be planned to run when outer casing 13 3/8" are drilled and 9 5/8" casing is still to be drilled.

In the absence of any data from CPET or corrosion logs, the following shall be applied for definition of protection criteria (CP criteria shall be based on achieving a measured return current):

(a) **Onshore Well Casings**:

CP system shall be designed to provide for a single well casing a minimum of 20A of dc current per well and for multiple/clusters of well casings a minimum of 25A of dc current per well.

Return current from each well shall be measured and shall meet a minimum of 15Amps.

(b) **Artificial Island (Offshore) Well Casings**:

The CP system shall be designed to provide a minimum of 20A of dc current to each well casing.

Coated well casing return current from each well shall be measured and shall meet a minimum of 8-12 Amps

Bare well casing return current from each well shall be measured and shall meet a minimum of 15-20 Amps

32.3 Design Life

The cathodic protection system design life shall be equal to or exceed the design life of the structure being protected.

Minimum design life for well casing CP systems, shall be as follows:

- Permanent ICCP system – 30 years,

32.4 Anode/Groundbed Parameters

32.4.1 Anodes

Anodes for use in the protection of well casings shall be as follows:

- Mixed metal oxide (MMO) coated titanium tubes (ICCP)

The MMO/titanium anode shall have the following design parameters:

Table 76 – Well Casings - MMO/Titanium Anode Design Parameters

MMO/Titanium parameters - Tubular Anode	Design Values
Anode size (min)	25mm dia. X 1000mm long
Titanium	ASTM B338, grade 1
Current density (in carbonaceous backfill)	Max. 50 A/m^2
Current density (in calcined petroleum)	Max. 100 A/m^2
Current density (in sea water)	Max. 600 A/m^2

Notes.

(i) MMO/Ti current density values based on standard manufacturers values for a lifetime of 20 years. For different design life requirements, MMO/Ti anode current densities shall be adjusted accordingly.

32.4.2 Groundbeds

The CP design for well casings shall be based on protection by an ICCP remote groundbed system.

Anode groundbeds shall be in the form of onshore deep well groundbeds or, if the wells are located in a suitable coastal area, offshore seabed pyramid type anodes may be proposed. Anode groundbeds shall be selected in a way to have uniform current distribution and minimize interference. The circuit resistance current balancing shall be achieved using different sizes / lengths of negative cables. Use of variable resistors shall be avoided. However, if during pre-commissioning testing, current balancing is not achieved, variable resistors may be used subject to ADNOC approval.

Groundbeds shall be designed to have a resistance to remote earth of less than 1.0 ohm and to fulfil anode current output characteristics under normal soil/sea water conditions.

The resistance of groundbed shall be limited to 0.6 ohm when solar power unit is being used as the DC power source (up to 20 Amps). The resistance of groundbed shall be limited to 0.3 ohm for DC output between 20-40 Amps). This is to limit the solar power voltage to 12 V.

For very deep ‘onshore’ borehole groundbeds (>100m) data on nearby groundbeds and water table depth may be used to design new groundbeds. In such cases, data and design shall be subject to COMPANY confirmation and approval.

The active column of the deep ‘onshore’ anodebed shall be 10m below the static water table.

For ‘offshore’ groundbeds, maximum voltage between anode material and electrolyte (in sea water environments) are given in EN 13174 as 8V. However, it should be noted that this is applicable for exposed titanium and that fully platinised or MMO coated titanium will be capable of supporting much higher voltages.

NACE Corrosion Paper 2107, indicates that fully coated titanium based anodes will be capable of operating upto 50-60V without signs of ‘breaking potential’ being reached

The groundbed of an impressed current cathodic protection system shall be designed such that:

- Its mass and material quality or rated current capacity is suitable and sufficient to last for the specified design life and current of the CP system
- Its resistance to earth allows the maximum predicted current demand to be met at 80% or less of the voltage capacity of the DC source during the design life of the system
- Its location is remote from the well casing and any other buried structure, to provide a regular distribution of current along the well casing
- Groundbed (onshore) shall not be installed immediately below high tension overhead transmission lines
- The risk of causing harmful interference on other buried structures is minimized
- The capacity of the anodebed is more than or equal to the maximum current ratings of the DC power source

32.5 Design Resistivity

Design resistivity values for onshore CP systems shall be based on the soil resistivity measurements recorded during pre-design site surveys.

For offshore installed anodes, the resistivity of the electrolyte for anode/CP system sizing shall be as per the below table. Sea water resistivity shall be used if the anodes are free from the risk of sand blockade and sea mud resistivity shall be considered for buried or partially buried anodes. The below table shall be the conservative resistivity values to be used for anode sizing.

Table 77 — Well Casings - Conservative Design Resistivity of ADNOC Offshore

Electrolyte	Design Resistivity Values
Sea water (Non-buried)	15 Ω-cm
Sea mud (Anodes are buried or partially buried)	60 Ω-cm

32.6 Current Density

The minimum current requirement for design purposes of the external cathodic protection of the well casing to the required depth will be determined by the following means:

- Eoff - log I curves obtained on at least one, and preferably more, of each type of casing completion, on a similar terrain, for the given field.
- CPET / CPP log data obtained on at least one, and preferably more, of each type of casing completion, on a similar terrain, for the given field
- Average current densities: literature data may also be used to calculate the amount of CP current required to prevent external corrosion.
- Mathematical procedures as described in e.g. in EN 15112, or equivalent,

Whenever available, Eoff – log I or CPET / CPP log for the particular ADNOC Onshore or Offshore field (for Island well casings) shall be provided with the SOW for design of the well casing cathodic protection system. It shall be assessed if the wells under the scope are in the same soil environment for this data to be used. It shall be ensured that the casings are allowed to polarize for a minimum of one (1) week before CPET/ CPP logs are run.

In the absence of any data from CPET or corrosion logs, the CP system shall be designed to provide a minimum dc current to each well and to have a minimum return 'drain' current from each well as per that detailed in sec. 32.2.

32.7 Coating Breakdown Factor

Application of a coating breakdown factor in the CP design calculation is not applicable, as the CP design will be based on the application of a minimum dc current to each well as per that detailed in sec. 32.2.

32.8 Surface Area

Consideration of the well casing surface area in the CP design calculations is not necessary as the CP design will be based on the application of a minimum dc current to each well as per that detailed in sec. 32.2.

32.9 Monitoring Facilities

32.9.1 Cable Connection to Well Casings

The cable connection to the well casing shall be designed to ensure adequate mechanical strength and electrical continuity and to prevent damage to the structure.

Cable connections shall not be carried out within 300mm from the welds.

A separate connection shall be made for each cable. The minimum separation between two connections shall be 300mm.

All cable connections shall be fully encapsulated to comply with the original coating standards.

The following methods shall be used for cable connections:

Table 78 — Well Casings - Cable Connection Methods

Structure	Method of cable connection	
	Current Carrying Cable	Monitoring Cable
Well casings	Welded Pad	Welded Pad

32.9.2 Monitoring Facility Types

Monitoring of the effectiveness of the CP system applied to well casings shall be by measurement of the return 'drain' current from the well and not by the potential measurements recorded on the well casing.

Current drain measurements shall be made at negative junction boxes incorporating the main negative cable from the DC power supply and negative drain cables from the well casing(s) protected. Each negative circuit to include an appropriate rated shunt to directly measure the return current to ensure compliance with sec.32.2.

Although, test facilities are not required for measurement of well casing potentials, where isolating joints / insulated flanges are installed between flowlines and well casing (see sec.32.11) then test facilities in accordance with sec 21.9 (b) shall be installed.

32.10 Interference

32.10.1 DC Interference

CP systems of adjacent structures can interfere with the protected structure.

DC interference can lead to accelerated corrosion of affected structure.

The CONTRACTOR shall investigate possible sources of detrimental DC stray currents and include proposals in the design on how to mitigate the effect of such stray currents on the protected structure.

CONTRACTOR shall carry out a stray current survey at the time of commissioning.

For interaction effects on secondary structures as a result of the CP system on the protected structure, the following shall be applied:

(a) On secondary structures without a CP system, maximum positive potential change on any part of the secondary structure, resulting from interaction, should not exceed 20 mV. In case a positive swing of more than 20 mV, mitigation measures shall be adopted by the CONTRACTOR

(b) On secondary structures with a CP system, unacceptable interference shall be deemed when the 'Polarized' potential on the secondary structure does not achieve the protection potential range as per Table 1.

32.10.2 AC Interference

AC interference is not considered an issue for well casings.

32.11 Electrical Isolation

It is preferable to have no electrical isolation at the well heads for oil and water flowlines. For Gas flowlines, either wet or dry, electrical isolation shall be provided. Table 79 defines the requirements for electrical isolation between the well to be protected and the corresponding flow-line.

Table 79 — Well Casings - Electrical Isolation Requirements

FL Internal Environment	Requirement
Dry Gas	Electrical isolation with spark arrester
Wet gas	
Oil	No IJ required at the well head / FL connection
Water	No IJ required at the well head / FL connection

(a) For dry gas applications the electrical isolation shall be made through a Monobloc isolating joint.

(b) For wet gas applications isolating spools shall be used.

Isolating joints / isolating spools shall be in accordance with that detailed in Annex I.

The insulating device shall be located above ground or in non-floodable manholes, on a straight section of the pipe, and design permitting, in a vertical or sloped plan, when the pipeline leaves or enters the ground, in order to avoid any risk of internal short circuit of insulating parts by internal deposits.

Electrical isolation devices currently installed between the wellhead and the externally coated buried gas flowlines will remain, provided an integrity assessment is performed and provides good results.

If, in the course of the life of a Gas well, initially provided with isolation, a significant increase in the quantity of electrolytic conductive fluids – increase in WGR – is observed, and the insulation is not realistic, both the flowline and the deep well casings shall be made one single CP system.

Because wells have very low resistance to earth, a device in accordance with NACE SP 0177 should be installed to protect the isolating joint against over voltages. Safety devices such as surge diverters are allowed.

A test post of the type described in sec 21.9 (b) shall be installed whenever a monolithic isolation joint or an isolation spool is installed allowing to monitor the performance of the IJ.

This may also be required in the case the well is subject to the influence of stray currents. The bonding of the isolating joint (with or without resistor) can sometimes allow the installation of a drainage point on the flowline to mitigate the influence of the stray currents.

Whenever wells are provided with ESP´s having an independent earthing, they shall have the ESP electrically connected through a solid state polarization cell.

Electrical isolation between the well casings and the rebar of the cellar shall be ensured.

Note.

All casings and conductors shall be made electrically continuous to ensure effective CP of well casing

32.12 Anode Installation Procedure

Anode groundbeds shall be in the form of onshore deep well groundbeds or, if the wells are located in a suitable coastal area, offshore seabed pyramid type anodes may be proposed. Anode groundbeds shall be selected in a way to have uniform current distribution and minimize interference. The circuit resistance current balancing shall be achieved using different sizes / lengths of negative cables. Use of variable resistors shall be avoided. However, if during pre-commissioning testing, current balancing is not achieved, variable resistors may be used subject to ADNOC approval.

In the case of deep well groundbeds, the current per groundbed shall not exceed 100 Amp. Offshore / subsea pyramid anodes can operate at higher current outputs up to 300 Amp with maximum 150 A current per anode.

The spacing between anodes and isolated foreign structures should be a minimum of 150m (200m for seabed anodes). Isolated foreign structures should not be located within the voltage gradient of the anode. If this is unavoidable then the Contractor shall demonstrate on commissioning that no unacceptable interference is occurring.

Positioning of the groundbed, there should not be any buried metallic structure at the groundbed location and between the groundbed and the pipeline being protected. The groundbed shall be placed so as to maintain the following minimum separation:

1. Groundbed to the structure being protected

The minimum spacing between the anode groundbed and the well casings shall be 100m. This distance shall be increased if voltage gradient calculations at the rated output do not show that 100m is adequate for the anode to be remote.

2. Groundbed to any foreign buried structures:

Preferred minimum separation is 150 m for onshore groundbeds (200m for seabed anodes). However due to space limitation, it may not be feasible to maintain 150 m separation in all the cases. In such case, the distance of the foreign structure and groundbed depends upon the resistivity of soil where groundbed is installed and current output of groundbed. The following guidelines shall be followed:

Table 80 — Well Casings - Groundbed Current Output

Minimum distance of structure to	Groundbed Current Output (Amps)			
	0-20	21-40	41-60	61-80
Deep Groundbed (m)	35	65	95	125
Surface Groundbed (m)	65	125	190	250

Notes:

(i) The calculations are based on 500 ohm.cm soil resistivity for deep groundbed and 1,000 ohm.cm for Surface Groundbed.

(ii) Surface groundbed separation is applicable for existing groundbeds.

(iii) In case of higher resistivity, the distance shall be increased proportionately. It shall be reviewed and approved by COMPANY.

3. Groundbed and existing anode groundbeds (excluding close anode systems) :

Preferred distance is 100 m. However if it is not feasible, minimum separation of 50 m shall be used. Crowding factor of 1.1 m shall be used to calculate resistance of each groundbed and corresponding voltage of DC power source. Crowding factor of 1.05 shall be used for 100 m spacing.

Where groups of structures exist, shielding may occur. In such instances, it is sometimes desirable to distribute groundbeds such that the minimum separation is less than that given above. COMPANY shall be consulted in such case and approval shall be obtained before construction.

In any event the cable connecting the CP power supply and its associated groundbed(s) should be minimized and shall not exceed 500 m.

4. Distance from High Voltage Overhead Transmission Lines

It shall be ensured that the groundbed is not constructed immediately below any overhead transmission line. The minimum lateral separation shall be:

Table 81 — Well Casings - Minimum Separation Between Groundbed and Overhead Lines

OHL rating (KV)	33	>33
Min. separation between groundbed and OHL (m)	100	150

32.13 Pre-Commissioning and Commissioning Procedures

The CONTRACTOR shall perform all pre-commissioning tests in the presence of COMPANY personnel to confirm satisfactory installation and operation of all equipment. Such tests shall include trial operation of power sources to their maximum capacity and measurement and checking of all cathodic protection circuits to confirm satisfactory connection and identification. Tests shall include resistance to earth tests of new groundbed anodes, testing of isolation joints and insulated flanges.

CONTRACTOR shall document the results of all tests for inclusion in the commissioning manual.

Commissioning procedures are required to prove that the installed cathodic protection system is in accordance with the design. This document shall include as a minimum:

(a) Procedures for the testing of well casing isolation

(b) Procedures for natural potential surveys

(c) Procedures for energizing cathodic protection hardware

(d) Procedure for testing and adjustment of dc current flow and drain (to meet criteria, sec. 32.2)

(e) Procedures for full ON / OFF potential surveys

(f) Procedures for interference testing

(g) Procedure for mitigation measures if interference is detected during the commissioning (if the positive swing on the foreign structure exceeds 20 mV)

(h) A time schedule for the commissioning of the system, where applicable in conjunction with the construction or commissioning schedule of the pipeline

(i) Required format of the commissioning report

(j) Procedure for clearing the Punch List items

32.14 Operation and Maintenance

The effectiveness of the cathodic protection system is assessed by comparing actual measured values from the operation of the CP system with reference values or the protection criteria.

Measured values established at cathodic protection stations and monitoring facilities at the time of commissioning of the CP system shall be used as reference values.

During operation and monitoring of the CP system, if there are indications that cathodic protection is not fully effective throughout the well casing, investigations should be carried out and appropriate corrective action taken to restore the effectiveness. Measured values established from this investigation shall then be used as the new reference values.

Minimum routine measurements and periodical checks to be undertaken during the operation of the CP system shall be in accordance with.

Table 82 ─ Well Casings - Minimum Routine Measurements and Periodical Checks

Item	Action Description	Period
Impressed-current station	Visual check of the TRU and reading of output voltage and current	One to three months
Impressed-current station	Comprehensive functional tests of the impressed current station e.g. verification of TRU, resistance determination of the groundbed, measurement of the earthing system, control of instruments, and measuring of the output voltage and current	One year
Negative drainage stations	Visual check of the negative drainage station and reading of the integral cathodic protection instrumentation	One to three months
Negative drainage stations	Comprehensive functional tests of the negative drainage station e.g. measurement of the drain point potential and return current	One year
IJ/IF test stations	Measurement of ‘CP ON’ potential (on both sides of electrical isolation)	One year
IJ/IF test stations	Measurement of potential ‘swing’ test at IJ/IF (electrical isolation integrity)	Three years

SECTION –E (appendices)

APPENDIX 1: CATHODIC PROTECTION MATERIALS AND EQUIPMENT

1 SCOPE

This appendix specifies the technical requirements for the major cathodic protection equipment where these are not fully covered by the main specification.

This is an extract from ADNOC CP Specifications.

2 ABBREVIATIONS

AC	Alternating Current
Ag/AgCl	Silver/Silver Chloride as used for the Silver/Silver Chloride type of reference electrode
AJB	Anode junction Box
CD	Current density
CP	Cathodic protection
Cu	Copper
$CuSO_4$	Copper Sulphate
DC	Direct current
DCVG	Direct Current Voltage Gradient (Survey)
DP	Drain Point
DFT	Dry Film Thickness
EMF	Electromotive Force
ER	Electric Resistance
EExd	Protective enclosure for electrical equipment (which can produce arcs/sparks) to EN 50014 and EN 50018 when located in hazardous flammable and explosive atmospheres
EExe	Increased safety for the above equipment which do not produce arcs or sparks

FBE	Fusion Bonded Epoxy (Coating)
FEED	Front End Engineering Design
FED	Front End Design
GA	General Arrangement
GRE	Glass Fibre Reinforced Epoxy (Coating)
GRP	Glass Reinforced Polyester
HALAR	Ethylene Chloro TriFluoroEthylene (ECTFE)
HMWPE	High Molecular Weight Polyethylene
HSE	Health safety and environment
ICCP	Impressed Current Cathodic Protection
IEC	International Electrical Committee
IF Kit	Isolation Flange Kit
IJ	Isolation Joint
IP	A code for protective enclosure type of electrical / electronic equipment as given in IEC 60529
ITP	Inspection and Test Plan
MMO	Mixed Metal Oxide
NACE	National Association of Corrosion Engineers
NDB	Negative Distribution Box
NJB	Negative Junction Box
OHL	Overhead Line
O&M	Operation and Maintenance
PCP	Permanent Cathodic Protection
PCR	Polarization Cell Replacement
PE	Polyethylene (Coating)
PP	Polypropylene (Coating)

PVC	Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
RE	Reference Electrode
ROW	Right of Way
SSP	Solid State Polarization Cell
STP	Standard Test Point
TCP	Temporary Cathodic Protection
TOR	Terms of Reference
TPI	Third Party Inspector or Inspection
TRU	Transformer rectifier unit
U/G	Under Ground
UPVC	Unplasticized Polyvinyl Chloride
XLPE	Cross Linked Polyethylene

3 NORMATIVE REFERENCES

National Association of Corrosion Engineers (NACE)

SP-0169	Control of external corrosion on underground or submerged metallic piping system
SP-0572	Design, Installation, Operation and Maintenance of Impressed Current Deep Ground beds
SP-0575	Internal Cathodic Protection (CP) Systems in Oil Treating Vessels
SP-0177	Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control
SP-0285	Corrosion Control of Underground Storage Tanks by Cathodic Protection
SP-0286	Electrical Isolation of Cathodically Protected Pipelines
SP-0388	Impressed Current Cathodic Protection of Internal Submerged Surfaces of Carbon Steel Water Storage Tanks
SP-0196	Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks

SP-0507	Standard Practice Pipeline External Corrosion Direct Assessment Methodology
SP-0207	Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines
RP-0104	The use of Coupons for Cathodic Protection Monitoring Applications
TM-0101	Measurement Technique Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Tanks
TM-0102	Measurement of Protective Coating Electrical Conductance on Underground Pipelines
TM-0497	Measurement Technique Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems

ASTM International

ASTM G57	Test Methods for Field Measurement of Soil Resistivity using the Wenner four Pin Method

ISO Standards

ISO-15589-1	Cathodic Protection of Pipeline Systems-Part 1 On-land Pipelines Code of Practice for Land and Marine Applications

DNV

DNV RP B401	Cathodic Protection Design

4 ENGINEERING MATERIALS AND EQUIPMENT

The following sections list the technical requirements of major CP equipment.

4.1 Transformer Rectifier (T/R) Unit

This specification covers the minimum technical requirements for the manufacture, inspection and testing of a semi-conductor, manual constant voltage / constant current, oil immersed, self-cooled transformer rectifier (T/R) for cathodic protection.

The transformer rectifier unit is required to provide a full wave rectified continuous and stable DC output from AC input.

Notes:

(i) Multichannel units (a TR unit having single AC input supply and more than one independent DC output) may be used for closely spaced structures in plants.

(ii) Each channel shall have independent anodebed(s). Output from more than one channel shall never be connected to a single anodebed.

(iii) Thyristor controlled auto potential units shall be used for the internal protection of water tanks. The output shall be based on the potential signal from the permanent reference cell (cell selectable from 3 cells installed at different elevations).

Reference standards:

Where referred to in this specification, the latest edition of the following standards shall apply.

In case of a conflict between the standards and the specifications, this specification shall take precedence.

IEC - 60076:	Power Transformers
IEC - 60947:	Low voltage switchgear and control gear
IEC - 60051:	Specification for direct acting indicating electrical measuring instruments and their accessories
IEC - 60269:	Low Voltage Fuses
IEC - 60227:	PVC-insulated cables (non-armoured) for electric power and lighting
IEC - 60331:	Tests for electric cables under fire conditions
IEC - 60464:	Varnishes used for electrical insulation
IEC - 60529:	Degree of Protection provided by enclosures (IP-code)
BS 148:	Reclaimed mineral insulating oil for transformers and switchgear
BS EN 60146:	Semiconductor converters

General:

The T/R shall be oil cooled and rated to operate at the specified output continuously.

AC input voltage may vary as per the situation and same shall be advised by the COMPANY. Preferred AC input supply is 440 V, three phase, 50 Hz. Single phase power supply may be used if three phase power supply is not available. However this shall be restricted to the T/Rs having a rated power output of less than 2500 Watts.

The DC output voltage and current shall depend on the system requirements and shall be worked out by the CP designer as per the system requirements and approved by COMPANY.

TR output shall be suitably designed and rated to avoid fluctuations at low DC outputs specially observed for three layer coated pipelines.

The unit shall comprise of an autotransformer, a main transformer, a rectifier and accessories for protection and metering. The auto transformer shall supply a continuously variable voltage to the main transformer which will step it down by a fixed ratio. The main components of the unit shall be as follows:

- Auto transformer
- Main transformer
- Rectifier
- Circuit protective devices
- Over voltage protection devices
- Meters
- Switches
- Wiring and cable terminals
- Current interrupters
- Oil tank

Housing:

The components shall be housed in a painted steel enclosure, divided into main sections; oil tank for the T/R unit and control cabinet for protection, control and instrumentation devices. Main construction requirements are as follows:

- T/R units shall be oil immersed and self-cooled (naturally cooled).
- The enclosure shall be dust and water proof. The minimum degree of ingress protection shall be IP-66. The unit shall be provided with a sun shade.
- The T/R unit shall be supplied complete with bolted type base frame, holding down bolts for outdoor plinth mounting. Lifting lugs shall be provided to facilitate lifting of the unit when filled with oil. The minimum thickness of the tank sheet shall be 3mm. The tank shall be filled with oil to leave a minimum air space. Front access to the controls shall be via a weather proof hinged lockable door. A clip type stainless steel lock shall be provided.

The unit shall be suitable for the environmental conditions prevalent as listed in section 4.

Notes:

(i) Wherever possible the T/R unit shall be installed in a non-hazardous area. If it is not possible, the construction of the T/R unit shall fulfil the requirements of the hazardous area classification applicable for the site. The CONTRACTOR / MANUFACTURER shall obtain the required information on area classification from the COMPANY.

(ii) MANUFACTURER shall furnish TR Data sheets, GA, Schematic and installation drawings. Installation drawing shall show the foundation and cable entry details.

Main Transformer:

Main transformer shall be double wound core type in accordance with IEC60076. It shall be continuously rated at full load and provided with continuous variation by means of “Variac” type auto transformer connected to the transformer primary.

An earth shield shall be placed between primary and secondary windings of the main transformer.

The transformer efficiency shall not be less than 95% at full load.

Note: “Variac” transformer shall not be used for auto potential units. Thyristor controlled outputs, based on the potential signal from three (3) reference cells shall be used in auto potential units.

Rectifier:

The rectifier elements shall be silicon diodes connected for full wave rectification using a bridge circuit in accordance with BS EN 60146. The bridge rectifier assembly shall be 110% continuously rated at the transformer rectifier full load current and voltage at the maximum ambient temperature specified and 200% rated for one minute following 110% rated load.

Silicon diodes used in the bridge rectifier shall be rated to provide an adequate margin for over voltage and current surge and peak inverse voltage rating shall be 1.2 kV. The diodes shall be provided with over voltage and current surge protection circuits which shall operate at a voltage of less than 1.0 kV. High speed fuses shall be provided between the transformer secondary and the rectifier bridge.

The units shall be fitted with smoothing filter circuits to ensure the output does not contain more than 5% ripple.

The overall efficiency of the transformer rectifier shall be above 80% at full load.

AC Isolator:

An isolator shall be provided to facilitate switching off of the AC power supply to the transformer rectifier unit.

AC input switch fuse:

A suitably rated AC switch fuse shall be supplied mounted on the tank or inside the T/R control box. The connection of the AC input to the internal wiring of the transformer shall be made in mineral insulated copper sheathed conductor or in PVC insulated and sheathed copper cables in conduit. The switch fuse shall be capable of being locked in the ‘ON’ or ‘OFF’ position.

Control box:

Controls and indicators shall be housed in a control enclosure mounted on the front of the tank at safe working height without recourse to a platform structure. Access to the control panel shall be via a hinged, lockable door suitably stiffened to prevent distortion. Clip type lock made of stainless steel shall be provided. The controls, instruments, indicators, control fuses and voltmeter fuses shall be mounted on a hinged panel inside the enclosure.

The control board and terminal shall be mounted behind the hinged control panel, thus being shielded from accidental contact during normal operations.

The enclosure shall have a Makralon or approved equivalent viewing window to permit observation of all instruments without opening the enclosure door. The edges of the enclosures shall be fitted with a neoprene gasket seal suitable to prevent the ingress of moisture or dust in the conditions prevalent at site. Not more than four screwed fixings shall be used to secure the control enclosure door. Alternatively quick release catches shall be used to secure the control enclosure door.

These fixings shall not be less than M10 coarse threads. The enclosure shall be protected to IEC-60947.

DC output regulation:

Suitable output regulation equipment shall be provided to allow for a step less (continuous) on load variation of the output from zero to the maximum rated output. The controls shall be easily accessible within the control box.

Remote Monitoring:

Based on the Project requirements, the T/R unit shall have the provision of Remote Monitoring. It shall be equipped with transducers (4-20m Amps analog signals) for transmission by telemetry system of the following parameters:

- Output DC current
- Output DC voltage
- Structure-to-electrolyte potential at the drain point

Note:

Other modes of remote monitoring using Satellite / GSM based wireless communication are acceptable as per the project specifications.

Instruments - Ammeter and Voltmeter:

A hermetically sealed moving coil DC ammeter / voltmeter to IEC 60051 shall be vertically mounted on the control panel. It shall be connected to facilitate the measurement of full output direct current / voltage of the transformer rectifier unit. The instrument range shall be of a preferred value to IEC 60051 and the scale shall indicate the full output rating of the unit at not less than 70% of full scale. The instrument scale shall be a minimum of 75mm in length and the meter shall have an accuracy class index of 1.5 or better. A red line shall indicate the maximum output. Metal cased instruments must be earthed.

Fuses:

A HRC fuse to IEC 60269 rated at the maximum unit output current shall be provided in the DC output circuit.

Fuses shall be cartridge type and mounted on the panel for easy accessibility. Voltmeter shall be protected by a suitably rated fuse placed in both negative and positive leads.

AC supply fuses shall be located in the incoming switch fuse box.

All cartridge fuses shall have spares located on the panel or on the inside the enclosed door.

DC output terminals:

Positive and negative output terminals shall be mounted in a suitable position for easy access and cable connection either in the control box or in a separate enclosure to the same specification. The number and sizing of the terminals shall be as per the project requirements and COMPANY's instructions. As a minimum each DC output shall have two negative and two positive terminals.

All terminals shall be fully insulated from the metal of the tank. The terminals shall not be less than M10 brass bolts each provided with nuts, lock nuts, washers and cast brass cable lugs suitable for the specified positive and negative single core copper conductor cables.

The terminals shall be clearly marked to indicate the polarity with “+ve Groundbed” and “-ve Structure” labels engraved to provide black letters on white background.

Additional terminals and switch arrangement shall be fitted such that a portable synchronous timer may be used on the unit without the need for disconnecting either DC output or input cables. These terminals shall be clearly marked with “+ve Timer” and “-ve Timer”.

The box shall be drilled for vertical bottom entry. Brass compressions type cable glands for the specified cables shall be fitted.

Current Interrupter:

The unit shall be supplied with an electronic ‘timer switch control’ capable of operating cyclically with a variable time period for ‘ON’ and ‘OFF’ between 0.1 second and 100 seconds.

A double pole changeover switch shall be provided on the front of the equipment to enable selection to be made of either time switch controlled or continuous operation. During the normal operations timer shall be bypassed.

Note: If a pipeline system is cathodically protected by more than one transformer rectifier, all T/R units should be provided with GPS synchronous interrupters.

Circuit protection:

The equipment shall be provided with appropriate input and output circuit protection e.g. with semiconductor fuses. In particular the positive DC output shall be provided with a suitably sized semiconductor fuse prior to anode connection and cathode circuit shall be fused similarly.

A surge diverter shall be connected across the DC output of the unit. This shall be suitable for protection against surges caused by lightning, AC or DC fuse rupture or AC switching. The diodes being used in the rectifier must have a Peak Inverse Voltage rating above the voltage rating of the surge diverter. A surge diverter shall be installed on the AC input side also.

A suitably rated, ambient compensated, moulded case circuit breaker (MCCB) shall be provided on the mains input to provide short circuit and thermal overload protection. A suitable over temperature trip device shall be included which shall trip the main AC supply if the temperature within the unit reaches an unsafe value. The trip shall operate at 700 C.

The thermostat shall be factory set at the required temperature for safe operations and shall be capable of adjustment.

Two spare sets of all the fuses shall be mounted inside the control enclosure.

Wiring:

Inter-component conductors shall conform to IEC-60227 and the flame retardence of the insulation shall comply with the requirements of IEC-60331. Oil immersed wiring should be oil resistant and able to withstand the high temperature.

The cross sections of the copper conductors and cable terminations shall be such that the maximum rated current carried shall not cause excessive voltage drops or temperature rises in the equipment.

All cable terminations and terminal connections of the components shall be of adequate cross section and vibration proof.

All terminals and equipment operating at voltage levels likely to cause electric shock shall be insulated or screened from accidental contact.

All wires shall have ferrules at both ends.

Identification plate:

An identification plate of dimensions 150mm x 100mm shall be fitted on the exterior of the control box door engraved black on white materials as follows:

CATHODIC PROTECTION

Oil:

T/R shall be supplied with the first complete filling of oil complying with BS-148.

Spare and auxiliary fittings:

The T/R shall be supplied complete with all fittings necessary for operation and maintenance. These shall include, but not limited, to the following items:

(a) Steel channel under the base for plinth mounting. Channel shall be 100mm and shall have large holes at either end to enable unit to be pulled

(b) Nameplate, to be bolted or riveted stainless steel, Type 316, engraved or stamped in an easily visible exterior location. The name plate shall indicate the following as a minimum:

1. Manufacturer and Address
2. Descriptive Name: “Cathodic Protection Constant Voltage Transformer Rectifier”
3. Manufacturer’s Serial Number
4. ADNOC Onshore Purchase Order No. or Project Name

5. Input Rating:

   i. KVA

   ii. Nominal Voltage

   iii. Current

   iv. Single or Three phase

   v. Frequency (Hz)

6. Output Rating

   i. KW

   ii. Voltage

   iii. Current

7. Rectifier Material

8. Maximum Working temperature

9. Weight Without Oil

10. Oil Capacity

   i. Litres

   ii. Type

11. Date of Manufacture

(c) Lifting Lugs - welded on to the unit to facilitate the lifting of unit

(d) Earthing terminal - to be fitted externally, comprising an M10 coarse threaded stud complete with nut, locknut, washers and cast brass cable lug suitable for connection up to 35mm2 copper earth conductor.

(e) Valved oil drain, draining from base of tank, suitably protected from mechanical damage.

(f) Oil tank breather with dust filter and silica gel desiccator cartridge complete with spare silica gel cartridge.

(g) Oil filling hole with screw cap.

(h) Oil site gauge such that oil level is viewed through a flat toughened glass window in front of a white plastic sheet. The gauge shall be engraved with minimum oil level indication.

(i) Removable dial type thermometer graduated in degrees Celsius with a red on the scale indicating maximum oil temperature.

(j) A printed & laminated schematic diagram of the equipment circuitry attached to the inside of the control box door.

(k) Cable glands providing water tight seal for bottom entry of the specified cables.

(l) Two sets of keys necessary for securing and operating the unit.

(m) Set of spare fuses.

(n) Bolted on sun-shade capable of shielding all exposed surfaces of the tank up to 15 degrees from vertical.

Coatings:

Transformer Rectifier unit steel surfaces shall be coated in accordance with ADNOC Onshore Painting and Coating standard ES 30.99.37.0013.

The final paint color shall be light grey to RAL colour no. 7036.

Construction:

All coils of transformers, chokes, transducers, wire wound resistors etc. shall be fully impregnated with suitable oil resistant insulating varnish. This shall be either done by vacuum application or by preheating to a minimum of 100°C, fully immersing the coil in varnish while still hot, allowing the coil to cool in varnish and then oven drying. All procedures to be in accordance with the varnish manufacturer's instructions.

All assembled electrical components which will not be oil immersed, either in transit or under normal operating conditions, shall be dipped or double coated with a suitable air drying fungicide-bearing varnish conforming to BS EN 60464. This shall include the permanent wiring and connections of all control panels and metering boxes and all coils that have previously been impregnated with non-fungicidal varnishes before assembly.

All instruments such as ammeters and voltmeters shall be hermetically sealed and either flush mounted under the oil level or flush mounted on a panel with all back connections adequately coated with fungicide-bearing varnish.

Electronic component assemblies, particularly those including semi-conductor based items, shall be encapsulated in epoxy resin or varnishes which shall be approved by the component MANUFACTURER.

Insulating Materials:

All varnishes, insulating films, types and boards shall conform to the relevant standards and shall be fully compatible for the conditions to be encountered. Varnishes having a linseed oil base are not permitted. Cut or machined surfaces and edges of resin-bonded organic based laminates shall be smoothed and cleaned and then sealed with a varnish approved by laminate manufacturer. All fabric, cork and paper insulation materials shall be either protected by impregnation or with a suitable fungicide. Hygroscopic materials shall not be used for covering the coils, for insulation of interleaving, unless prior to use they are suitably impregnated with varnish. The use of wood in the equipment is not permitted.

Fixtures and fittings:

All hinges, fixings and items liable to fretting or mechanical damage of coatings during the service shall be manufactured from non-corrosive materials or 316stainless steel.

Test at manufacturer's works:

All instruments shall be to IEC-60051 and shall be certified as being batch calibrated and accurate with the classification of IEC-60051.

The transformer rectifier shall satisfactorily pass the following tests and the test results shall be recorded as per BS EN 60146.

(a) All circuits and apparatus shall withstand Power Frequency Voltage tests at 2000 Volts for one minute as follows:

1. AC to Earth
2. DC to Earth

(b) 1000 V Megger Insulation test comprising:

1. Primary to Secondary
2. Primary to Earth
3. Secondary to Earth
4. DC positive to Earth
5. DC Negative to Earth

(c) The unit shall be connected up and run for at least 24 hours continuously at maximum current and voltage outputs. The oil temperature shall be recorded throughout the test period at sufficient frequency to prove that equilibrium is reached during the test period. The 1000 V insulation test shall be repeated immediately at the conclusion of the continuous 24 hours test run.

(d) Performance test to IEC-60076 – ratio, Polarity, no load current, no load losses, full load losses and impedance Volts.

(e) Efficiency test at 25%, 60% and 100% of maximum current output with a constant load resistance.

(f) Any other tests deemed necessary by the inspector to prove compliance with the specifications.

Three copies of the test certificate setting out the results shall be made available to the COMPANY. The tests specified are considered to be minimum requirements and SUPPLIER shall undertake all testing necessary to ensure the equipment meets the requirements of this specification.

Third party inspection:

The COMPANY shall, at no cost to SUPPLIER, arrange a Third Party Inspection / Inspection by COMPANY representative which will cover:

- Review of test reports and certificates, materials and spare parts list, availability of drawings, operating manuals and other instructions
- Visual inspection of overall condition, packing and preservation
- Witnessing of tests carried out at MANUFACTURER's works

Spares Back-up:

A list of recommended spare parts required for a period of two years of operation shall be provided. Supply of these spare parts shall be included with each unit.

Documentation:

The T/R unit shall be supplied with two copies of an instruction manual detailing the installation, commissioning, operation and troubleshooting of the unit. This manual shall also comprise copies of the unit specification and circuit diagrams, general arrangement and an installation drawing, a parts list with part numbers and a copy of the test certificate.

Shipping:

In general all necessary precautions shall be taken in packing to avoid damage during transportation and handling.

Steel supports, conduits, externally mounted devices and other such items shall be supplied separately for site assembly.

4.2 Solar Power Unit

Solar power units shall follow Requirements of ES 30-99-53-0041 "Engineering specification for solar power supply system".

More than one DC output shall never be connected to a single anodebed. Number of anode beds shall always be equal to or more than outputs of solar power system.

This section covers specifications of Cathodic Protection Control unit.

Cathodic Protection Control Unit

The cathodic protection control unit shall be of pulse width modulation type which incorporates the following protection devices; protection to over-current, short circuits and transient voltage effects. Modern power control devices shall be used.

The CP control unit shall incorporate, but not be limited to:

(a) upper limit load current setting,

(b) voltmeter and ammeter for the output power,

(c) a variable timer of 0.1 up to 100 seconds which operates on the `ON' and `OFF' cycles for the CPU output current,

(d) a voltmeter and ammeter for load voltage and current and one voltmeter for reference cell voltage setting, resolution and accuracy of the meters shall be better than 2% of the full scale reading,

(e) on-board test facility for checking correct function of the cathodic protection control unit,

(f) the whole unit shall be tropicalised and fully enclosed in a weatherproof enclosure manufactured to BS EN 60529 protection category IP66, proof against damage by dust and water. It shall be lockable for security. The enclosure shall be GRP or 316L SS.

Remote Monitoring:

The solar unit shall have the provision of Remote Monitoring. It shall be equipped with transducers (4-20 mA analog signals) for transmission by telemetry system of the following parameters:

(a) Output DC current

(b) Output DC voltage

(c) Structure-to-electrolyte potential at the drain point

Note: Other modes of remote monitoring using Satellite / GSM based wireless communication are acceptable as per the project specifications.

Cable terminals for CP

The cathodic protection control unit shall have one positive and one negative output terminal in a suitable position for easy access and cable connection in the control box. The terminals shall not be less than M10 brass bolts each provided with nuts, locknuts, suitable for minimum 70mm^2 positive and 70mm^2 negative single core copper cables.

The terminals shall be clearly marked to indicate polarity with `+ve Groundbed' and `-ve Pipe' signs indestructibly engraved on white materials filled with black material.

The control box shall be drilled for vertical bottom entry. Brass weatherproof pressure glands for two 70mm^2 XLPE/PVC (or large cable as per the design) single core copper cables shall be supplied and fitted.

All cable connections with a cross sectional area of 35mm^2 or greater, shall be made using cable lugs and M10 threaded brass studs and nuts mounted on an 8mm thick non-conducting phenolic resin (or similar) board. Cables with a cross sectional area of less than 35mm^2 shall be connected using cable lugs and M8 threaded brass studs or `Klippon' type cable connections.

All cables shall be adequately supported by cable trays or cable conduits and shall run at least 10 cm above grade.

Note: It shall be ensured that battery banks are charged to 100% capacity before installation (5 complete charge / discharge cycles are recommended to reach full capacity of battery)

4.3 Anodes

This section defines the requirements of the Impressed Current or Sacrificial Anodes which shall be used for the CP systems as per the design requirements.

4.3.1 Impressed Current Anodes

Impressed current anodes shall be used for the protection of buried pipelines, tank bottoms and internal wetted surface, buried vessels and well casings.

a. Titanium Mixed Metal Oxide Tubular Anodes

Mixed Metal Oxide (MMO) shall consist of titanium tube substrate; titanium shall conform to ASTM B338, grade 1. MMO coating shall be applied to titanium substrate. MMO coating shall comprise of Iridium Oxide and Tantalum Oxide. The MMO coating shall be suitable for use in carbonaceous backfill, soil and water with high chloride content.

The anode coating should be tested by an independent laboratory for the current capacity and design life of the applied coating. Type test certificate of the coating shall be furnished by the MANUFACTURER.

The MANUFACTURER shall advise the current rating and life of the anode.

The minimum size of the anode for pipeline anodebeds shall be 25mm dia x 1000mm long. The minimum size of the anode for well casing anodebeds shall be 32mm dia x 1220mm long. Higher size of the anode may be used for anodebeds with higher current capacity e.g. anodebed for multiple well casings.

Each anode shall be supplied with 1 x 16mm^2 copper cable having Kynar (Polyvinylidene Fluoride, PVDF) or Halar (Ethylene Chloro TriFluoroEthylene (ECTFE)) insulation and HMWPE outer sheath. The anode shall be supplied with a sufficiently long cable so that it can be extended to the Anode Junction Box without splicing.

Multiple anodes on a common header cable shall not be used.

The cable shall be internally connected to the longitudinal center of tubular anode. The electrical resistance between anode and cable shall not exceed 0.001 ohm. The joint shall be completely sealed from both ends to prevent any ingress of moisture. The cable shall exit from one end. Additionally a heat shrink tube shall be applied to seal the end of the tube and cable where the anode tail cable exits. The other end shall be provided with a looped nylon rope to support end weight.

The anode shall be covered with a protective plastic covering to avoid any damage during shipping and handling.

The MANUFACTURER shall supply the test certificate of the base metal, type test certificate of accelerated corrosion test and certificate of conformity.

Anode Canister

For surface groundbeds, horizontal or vertical, and angularly drilled bore holes, anodes shall be supplied with canisters.

The canister shall be fabricated from galvanized sheet steel having a minimum thickness of 1.0mm. The canister dimension may vary based on anode size and installation. The recommended canister size is 150mm diameter x 1500mm long for a tubular anode of 25mm diameter x 1000mm long.

The anode shall be centrally located within the canister. The canister shall be completely filled with carbonaceous backfill. The ends of the canister shall be suitably sealed to prevent loss of backfill.

A plastic cable gland shall be provided in the canister cap for the protection of anode tail cable as it exits the cap.

b. Titanium Mixed Metal Oxide Ribbon Anodes

Titanium mixed metal oxide anode shall be used for the protection of the tank bottoms. These are used in conjunction with Titanium conductor bar and power feed connectors.

The anode ribbon shall be a titanium substrate to ASTM 265, grade 1 with mixed metal oxide coating of Iridium oxide and Tantalum oxide.

The anode width shall be 6.35mm (0.25”) and the thickness shall be 0.64mm.

The current capacity and design life of the anode shall be advised by the MANUFACTURER.

The anode shall be packed in a wooden / cardboard roll to avoid damage to the anode during shipping and handling.

The MANUFACTURER shall supply the test certificate of the base metal, type test certificate of accelerated corrosion test and certificate of conformity.

Note: MMO anodes shall not be used where temperatures are expected to be more than 80°C. CP CONTRACTOR shall use thermal gradient calculations to ensure that temperature is less than 80°C at anode installation depth. Higher anode installation depths may be used in such cases.

c. Titanium Conductor Bar

Titanium conductor bars are spot welded to the MMO ribbon anodes to form a grid. This helps to reduce the voltage drop along the ribbon anodes. These are also used to inject the CP current thru power feed connectors.

The conductor bar shall be made of titanium conforming to ASTM 265, grade 1.

The conductor bar width shall be 12.7mm (0.50”) and the thickness shall be 1.00mm (0.040”).

The conductor bar shall be packed in a wooden / cardboard roll to avoid damage during shipping and handling.

The MANUFACTURER shall supply the test certificate of the base metal and certificate of conformity.

d. Power feed

Power feed connectors are used to feed and distribute the CP current to anode grid. The basic power feed connector comprises of approximate 150mm long x 3mm dia titanium rod spot welded to 150mm long x 12.7mm wide conductor bar. It is connected to the required length of the cable in the factory and spot welded to the conductor bar in the field.

1x16mm^2 stranded copper conductor XLPE /PVC red cable shall be used as the power feed cable. The cable shall be of sufficient length to extend to the anode junction box without splicing.

The free end of the cable shall be provided with a cable tag identifying the power feed no. and the length in metres.

The cable shall be connected to the titanium rod using a copper sleeve. A proper crimping tool shall be used to make a good joint. The resistance should be less than 0.001 ohm.

The joint shall be water proof and following steps, as a minimum, are recommended for encapsulation:

(a) Cover the joint with rubber tape, overlap with Gel tape.

(b) Subsequently cover the entire joint with heat shrink tube, extending 25 mm on either side of the joint.

The powerfeed shall be supplied with test certificate showing the cable length, cable size, type and joint resistance.

e. MMO Piggy Backed Anodes

Titanium MMO piggy backed anodes shall be used for the protection of the tank bottoms. MMO wire is connected to the cable at regular intervals. Circular anode loops are placed between the HDPE liner and tank bottom, approximately 300mm below the tank bottom plate.

The anode wire shall be a titanium substrate to ASTM B 348, grade 1 with mixed metal oxide coating of Iridium oxide and Tantalum oxide.

The minimum anode diameter shall be 3.0mm.

The current capacity and design life of the anode shall be advised by the MANUFACTURER. The anode shall be connected to the anode tail cable (1x16mm^2 stranded copper conductor XLPE / PVC red cable) at intervals not exceeding 9 feet. At each joint cable insulation shall be removed. The anode wire shall be jointed to cable conductor using a C – crimp. A proper crimping tool shall be used to make a low resistance joint.

The joint shall be water proof and the following steps, as a minimum, are recommended for encapsulation:

(a) Cover the joint with rubber tape, overlap with Gel tape.

(b) Subsequently cover the entire joint with heat shrink tube, extending 25mm on either side of the joint.

The entire circular section of the cable in each loop shall be provided with wire anode. The two straight lengths of the cables shall exit thru a conduit in the ring wall and these shall be without anode.

The cable length shall be sufficient to extend to the anode junction box without splicing.

The anode MANUFACTURER shall supply the test certificate of the base metal, type test certificate of accelerated corrosion test and certificate of conformity.

The SUPPLIER shall supply the test certificate of anode loops showing cable length, cable size, type and joint resistance.

Note: MMO piggy backed anodes shall not be used where temperatures are expected to be more than 80°C. CP CONTRACTOR shall use thermal gradient calculations to ensure that temperature is less than 80°C at anode installation depth. Higher anode installation depths shall be used in such cases.

f. MMO Wire Anodes for internal CP systems

Titanium MMO anodes shall be used for the protection of the internal wetted surface of tanks containing water.

The anode wire shall be a titanium substrate to ASTM B 348, grade 1 with mixed metal oxide coating of Iridium oxide and Tantalum oxide.

The minimum anode diameter shall be 3.0mm.

The current capacity and design life of the anode shall be advised by the manufacturer.

The length of each anode shall be equal to maximum expected water level of the tank. No joint shall be permitted in the anode except the cable joint at the end. The bottom of anode shall be 500mm above the tank bottom. The top of the anode shall be 500mm above the maximum water level to keep the cable joint above the water.

One end of the anode shall be connected to the anode tail cable (1x16mm^2 stranded copper conductor XLPE / PVC red cable). The anode end shall be jointed to cable conductor using tinned copper sleeve and proper crimping tool.

The joint shall be water proof and following steps, as a minimum, are recommended for encapsulation:

(a) Cover the joint with rubber tape, overlap with Gel tape.

(b) Subsequently cover the entire joint with heat shrink tube, extending 25 mm on either side of the joint.

The cable length shall be sufficient to extend to the anode junction box, being installed at the tank roof, without splicing.

The anode MANUFACTURER shall supply the test certificate of the base metal, type test certificate of accelerated corrosion test and certificate of conformity.

The SUPPLIER shall supply the test certificate of anode showing cable length, cable size, type and joint resistance.

4.3.2 Sacrificial Anodes

Sacrificial CP systems shall be employed for the temporary protection of the pipelines during the construction, protection of buried section (at road crossings etc.) of surface laid pipelines, internal protection of tanks and vessels.

Test certificates:

For all sacrificial anodes the MANUFACTURER shall supply the chemical analysis and electrochemical test results. In addition to this the weight and dimension test certificates shall also be furnished. For pre-packaged anodes the test certificate shall also include the details of cable, prepackaged weight and dimensions.

The following anode electrochemical properties shall be considered

Anode Material	Potential (V)	Electrochemical capacity (Amp-hrs/ kg)
Aluminum	- 1.05 V w.r.t. Ag-AgCl	2500
Magnesium high potential alloy	- 1.75 w.r.t. Cu-$CuSO_4$)	1000-1180
Magnesium standard potential alloy	1.53 – 1.55 w.r.t. Cu-$CuSO_4$)	
Zinc	-1.1 w.r.t. Cu-$CuSO_4$)	740

a. Cast Magnesium Anodes

Pre-packaged Magnesium anodes shall be used for the external protection of the buried structures and bare cast magnesium anodes shall be used for internal protection of tanks.

Depending upon the applications, high potential or standard potential magnesium anodes shall be used. High potential magnesium anodes are recommended for high resistivity soils whereas standard potential anodes are suited for low resistivity soils (having resistivity under 2000 ohm-cms).

High Potential magnesium anodes

The high potential magnesium anode shall have the following chemical composition:

Element	Composition by weight (%) ASTM B843-18 (M1C)
Aluminium	0.01 max
Copper	0.02 max
Ferrous	0.03 max
Manganese	0.50 – 1.30
Nickel	0.001 max
Others (each)	0.05 max
Others maximum	0.30 max
Magnesium	Remainder

Standard Potential magnesium anodes

The standard potential magnesium anode shall have the following chemical composition:

Element	Composition by weight (%) ASTM B843-18 (AZ63B)
Aluminium	5.3 – 6.7
Copper	0.02 max
iron	0.003 max
Manganese	0.15 -0.70
Nickel	0.002 max

Silicon	0.10 max
Zinc	2.5 – 3.5
Others maximum	0.30 max
Magnesium	Remainder

Weight and Size of anode:

The anode weight and size shall be as per the system design requirements and as per industry standards.

b. Magnesium Ribbon Anodes

Extruded magnesium anodes shall be used in very high resistive environments.

It shall have the same chemical composition as high potential cast magnesium anode.

The anode size shall be as per the system design requirements. The minimum anode cross section shall be 19mm x 9.5mm (diagonal to diagonal). It shall be supplied with 3mm steel core. It shall be supplied in rolls for ease of installation.

c. Zinc Anodes

Pre-packaged zinc anodes shall be used for the external protection of the buried structures in low resistivity soils and bare cast zinc anodes shall be used for internal protection of tanks / vessels.

Pre-packaged zinc anodes are also used as grounding cells.

The zinc anode shall have the following chemical composition:

Element	Composition by weight (%) ASTM B418-16 Type	Composition by weight (%) ASTM B418-16 Type II
Aluminium	0.10 - 0.50%	0.005 max
Cadmium	0.025 - 0.07%	0.003 max
Copper	0.005% max	0.002 max

iron	0.005% max	0.0014 max
Lead	0.006% max	0.003 max
Others (total)	0.1% max-	-
Zinc	Remainder	Remainder
Use	Sea water/Brackish water or sea water sediment	Soil / fresh water

Weight and Size of anode:

The anode weight and size shall be as per the system design requirements and as per industry standards.

The minimum weight of zinc grounding cell shall be 27.2 kg. for grounding cell.

d. Zinc Ribbon Anodes

Extruded zinc ribbon anodes shall be used for the protection of carrier pipe within the casing. These are also used for the grounding of the pipelines affected by high tension overhead transmission power lines.

The zinc anode shall have the same chemical composition as cast zinc anode.

The minimum cross section of the zinc ribbon shall be 12.7mm x 14.2mm (diagonal to diagonal). Higher size of anode may be used as per the design requirements. It shall be supplied with 3mm steel core. It shall be supplied in rolls for ease of installation.

e. Pre-packaged Anode (Magnesium and Zinc)

Each anode shall be supplied with 1 x10mm^2 single core Copper / XLPE / PVC red cable. The cable length shall be adequate so that it can extend to test post / junction box without splicing (minimum recommended length is 8m).

The minimum cable size for the zinc grounding cell shall be 1x35mm^2.

The cable shall be properly connected to the anode core to have a firm joint with minimum resistance. The entire joint shall be sealed with a proper sealant to prevent the ingress of moisture.

The anode shall be pre-packaged in a cotton bag and filled with low resistivity backfill. The bag shall be adequately sized so that entire anode is covered with backfill. Supplier shall advise the dimensions of the pre-packaged anodes and these shall be in line with industry standard sizes.

The backfill shall have following chemical composition:

Element	Composition by weight (%)
Powdered Gypsum	75
Granular Bentonite	20
Anhydrous sodium sulphate	5

A tolerance of + 5% shall be allowed in each component of the backfill.

f. Aluminium Anodes

The aluminium alloy anodes shall be used for the internal protection of tanks and vessels containing low resistivity electrolyte. These shall also be used for the protection of external surface of subsea pipelines (bracelet anodes).

The aluminium alloy shall have the following chemical composition:

Element	Composition by weight (%)
Cadmium	0.002 max
Copper	0.003 max
iron	0.09 max
Indium	0.015 – 0.040
Silicon	0.12 max
Zinc	2.5 – 5.75
Others	0.02 max
Aluminium	Remainder
Use	Open sea water / brackish water / sediment

Note: For offshore applications, mercury content in the anode composition shall be nil (0%).

Weight and Size:

The anode weight and size shall be as per the system design requirements and as per industry standards.

4.4 Cables

This section defines the minimum requirements for single core, multi stranded copper DC cables.

The cables shall have stranded copper conductor. All cables shall be 600 / 1000 V grade as per IEC 60092-502.

No splices are allowed on buried cable. The minimum cable size, insulation shall be shall be as under:

Application	Minimum Conductor size mm^2	Insulation / Outer sheath	Outer Colour	Armouring
Monitoring – Structure side	10	XLPE/PVC	Black	
Monitoring – Plant side, foreign structure	10	XLPE/PVC	Red	
Sacrificial Anode tail cable	10	XLPE/PVC	Red	
Coupon cable	10	XLPE/PVC	Red	
Reference cell cable	10	XLPE/PVC	Yellow	
Bonding Cable – Structure side	16	XLPE/PVC	Black	
Bonding Cable –Foreign structure	16	XLPE/PVC	Red	
Anode header cable	16	Kynar or Halar / HMWPE	Black	
Powerfeed cable, anode	16	XLPE/PVC	Red	

header cable (internal anodes), cable for piggy backed anodes				
Zinc grounding cell	35	XLPE/PVC	Red	
Grounding cable at OHL mitigation	35	XLPE/PVC	Black	
Negative Header cable	50	XLPE/PVC	Black	SWA or AWA
Positive Header cable	50	XLPE/PVC	Red	SWA or AWA
Negative Header cable (Solar Power)	70	XLPE/PVC	Black	SWA or AWA
Positive Header cable (Solar Power)	70	XLPE/PVC	Red	SWA or AWA

Note: Positive and negative header cable size shall be increased based on the current demand and to limit the voltage drop to 10 % at maximum current output of DC power source. Armouring requirements shall be as per the project requirements.

Test Certificate: Cables shall be supplied with the original test certificate issued by cable MANUFACTURER.

4.5 Junction Boxes

Junction boxes play an important role for the control and monitoring of cathodic protection systems. This section covers the minimum materials and design requirements for various types of junction boxes.

Junction box enclosure

The junction box enclosures shall be fabricated from stainless steel type 316L. As an alternative the junction box enclosures may be of sheet steel construction.

Enclosure shall be painted in accordance with ADNOC Onshore Painting and Coating standard ES 30.99.37.0013.

Final colour shall be light grey to RAL 7036.

The enclosure shall be weatherproof and minimum degree of ingress protection shall be IP-55 in accordance with BS EN 60529.

For hazardous area applications the enclosures shall be of increased safety type, EExe or Explosion Proof, EEXd as per the area classification.

EExe shall be used only where no internal components other than terminals are used. In case components like shunt, resistor etc. are used, EEXd boxes shall be used.

EEXd enclosure shall be cast aluminium or cast steel. The minimum degree of protection for EEXe and EEXd enclosures shall be IP-66.

The enclosures shall be suitably sized to accommodate all components. These shall have sufficient room to dissipate the heat generated without overheating the components or enclosure. The enclosure shall be provided with a hinged door to provide easy access to all the internal components. Junction box shall be provided with stainless steel clip type lock.

The enclosure shall have as a minimum four nos. of external mounting lugs which can be used to fix the enclosure to a mounting frame. The enclosure shall not be punctured to mount it on the frame.

The junction boxes shall be provided with a 6mm thick phenolic panel to mount the components as per the system design. All cable entries shall be through properly designed and rated double compression cable glands. The enclosures shall be provided with gland plate(s).

Junction box mounting frame

Each junction box shall be provided with a mounting frame fabricated from suitably sized steel angles and flats. The minimum size of the angle shall be 50mm x 50mm x 6mm. The minimum height of the frame shall be 1.5m from the grade.

The frame shall have provision to fix it to the concrete foundation (Flat pieces shall be welded to the bottom of the frame and these shall have holes to fix these to the foundation).

The frame shall have horizontal flats to accommodate the cable tray for dressing the incoming and outgoing cables.

The entire frame shall be hot dip galvanized to protect it from atmospheric corrosion.

4.5.1 Anode Junction Box

Anode Junction Box (AJB) shall be used to monitor the anode current. It shall be provided with suitably rated shunts (recommended rating 100 mV = 10 A) to record the anode current by observing the potential drop across the shunt.

An identification plate, 100mm x 75mm, shall be screwed on the exterior of the door and engraved black on white material as follows:

CATHODIC PROTECTION

In addition, the following information, as applicable, shall be provided by the installation CONTRACTOR before handing over the system:

(a) Details of structure

(b) No. of anodes / powerfeeds, size and rating of each anode

(c) Shunt rating

(d) Resistor rating

(e) Date of commissioning

(f) Current output of each anode / powerfeed at the time of commissioning

(g) Depth of anodebed

These inputs shall be printed on a paper and the same shall be laminated. It shall be secured on the inner side of the door of the AJB.

4.5.2 Negative Distribution Box

Negative Distribution Box (NDB) shall be used to control and monitor the CP current being drained to each pipeline / structure.

It shall be provided with a suitably rated grid coil resistor and shunt (recommended rating 50 mV = 50 A). The current shall be controlled by varying the resistance of the variable resistor and it shall be monitored by observing the potential drop across the shunt. Each NDB shall be provided with an additional circuit to facilitate connection of additional pipelines / structures in the future.

An identification plate, 100mm x 75mm, shall be screwed on the exterior of the door and engraved black on white material as follows:

CATHODIC PROTECTION

In addition, the following information, as applicable, shall be provided by the installation CONTRACTOR before handing over the system:

(a) Detail of pipeline / structure

(b) Shunt and resistor rating

(c) Date of commissioning

(d) Current drained to each pipeline / structure at the time of commissioning

These inputs shall be printed on a paper and the same shall be laminated. It shall be secured on the inner side of the door of the NDB.

4.6 Test Post

Test facilities are needed for regular monitoring of the CP systems. Test post construction shall be suitable for the prevailing environmental conditions. The test post circuit shall be as per the type of monitoring facility. It shall have sufficient space for termination of test cables and for the installation of bonding cables, resistors and shunts etc. as per the system requirements.

Two types of test posts enclosures shall be used:

4.6.1 Big Fink Test Post

Big Fink type test post is to be used where no large component is required as per the circuit requirements.

Test post shall comprise of a terminal board, cap and base. The components shall be made of high strength polycarbonate. The colour of the big fink shall be Orange (RAL-2003). It shall be suitable for mounting on a 3" conduit. The test post head shall have a concealed link to lock it to the base plate.

It shall be provided with a minimum of five terminals for the termination of monitoring cables. The material of terminals shall be nickel plated brass or stainless steel.

A permanent identification plate shall be provided for each test post. It will have complete identification details covering the following info as minimum:

(a) Detail of pipeline / structure

(b) Pipeline Chainage

(c) Type of test post as per the circuit

(d) Shunt and resistor rating (as applicable)

The support post shall be hot dip galvanized steel pipe or UPVC pipe, 3" dia and minimum thickness shall be 5mm. The length of the pipe shall be 2m. The bottom 0.5m shall be covered with concrete foundation. The size of the foundation shall be 0.3 x 0.3 x 0.5m. Foundation shall be coated with bitumen to prevent ingress of moisture.

4.6.2 Bond Box Type Test Post

The junction box enclosures shall be fabricated from stainless steel type 316L. As an alternative the junction box enclosures may be of sheet steel construction.

Enclosure shall be painted in accordance with COMPANY Painting and Coating standard.

Final colour shall be light grey to RAL 7036.

The enclosure shall be weatherproof and minimum degree of ingress protection shall be IP-55 in accordance with BS EN 60529.

For hazardous area applications the enclosures shall be of increased safety type, EExe or Explosion Proof, EEXd as per the area classification. EEXd enclosure shall be cast aluminium or cast steel. The minimum degree of protection for EEXe and EEXd enclosures shall be IP-66.

The enclosures shall be suitably sized to accommodate all the components. These shall have sufficient room to dissipate the heat generated without overheating the components or enclosure. These shall be provided with hinged door to provide easy access to all the internal components. A clip type stainless steel lock shall be provided.

The enclosure shall have as a minimum four nos. of external mounting lugs which can be used to fix the enclosure to a mounting frame. The enclosure shall not be punctured to mount it on the frame.

The test post shall be provided with 6mm thick phenolic panel to mount the components as per the system design. All cable entries shall be through properly designed and rated double compression cable glands. The enclosures shall be provided with gland plate(s).

Test Post mounting frame

Each test post shall be provided with a mounting frame fabricated from suitably sized steel angles and flats. The minimum size of the angle shall be 50mm x 50mm x 6mm. The minimum height of the frame shall be 1.5m from the grade.

The frame shall have provision to fix it to the concrete foundation (Flat pieces shall be welded to the bottom of the frame and these shall have holes to fix these to the foundation).

The frame shall have horizontal flats to accommodate the cable tray for dressing the incoming and outgoing cables. The entire frame shall be hot dip galvanized to protect it from atmospheric corrosion.

4.6.3 Circuit Requirements

Each test post shall have the component as per the following requirements:

a. Monitoring Test Facility

Regular monitoring test facility shall have two monitoring cables from the pipeline / structure.

b. Test Facility across IJ

Test facility across IJ shall have four cables; two cables from the protected side and two cables from the unprotected side.

c. High Voltage Overhead Transmission Line Facility

The test post shall have one cable from PCR / SSP and two cables from the pipeline (1x10mm^2 for monitoring and 1 x 35mm^2 for grounding).

Note: If PCR / SSP have the provision of termination of monitoring cable, no separate test post shall be needed.

d. Internal Corrosion Monitoring Test Facility across IJ

In order to control internal corrosion due to current jump across an IJ or an IF, a test post shall be provided to facilitate the flow of current thru an external resistive circuit.

It shall have provision to control and monitor the current. It shall be provided with a variable resistor and shunt.

Note: This test post shall serve as test facility across IJ and hence no separate test facility shall be provided across IJ.

e. Drain Point Test Facility

Drain point test facility shall have a provision for the termination of two monitoring cables from the pipeline and two cables from the corrosion coupon. The test facility shall be provided with a reed switch and magnet to facilitate the monitoring of the "OFF" potential of the structure. A permanent reference cell shall also be installed at coupon test facility.

Note: Drain cable shall be connected to the pipeline near the drain point test post.

f. Coupon Test Facility

Coupon test facility shall be similar to the drain point test facility with the exception that there shall not be any drain cable at this facility.

g. Line Current Measurement Test Facility

Line Current Measurement test facility shall have a provision of termination of four cables. Two monitoring cables (black colour) shall be connected to the pipeline at the test post location. In addition to this two more cables (red colour) shall be connected to the pipeline at a distance of 100m downstream (in the direction of product flow) from the test post. All four cables shall be routed to the test post.

h. Foreign Service Test Facility

Foreign service test facility shall have a provision of termination of two monitoring cables (one each from pipeline and one from foreign pipeline, 1x10 mm^2) and two bonding cables (one each from pipeline and one from foreign pipeline, 1x16 mm^2).

It shall be provided with a variable resistor and shunt to facilitate the boning of two pipelines in the event interference is detected.

Note: In case of parallel pipelines, one additional test post shall be provided at existing ADNOC onshore pipeline to facilitate potential monitoring. It will have two cables.

i. Cased Crossing Test Facility

One test post shall have the cables from ribbon anode (for carrier pipe), pre-packaged magnesium anode (for Casing pipe), two cables each from carrier and casing pipe. The other test post shall not have any cable from the ribbon anode.

j. Uncased Road Crossing Test Facility

The test post shall have two monitoring cables from the pipeline / structure.

k. Road / Track / Fence / Pipeline Crossing Test Facility for Surface Flowlines

Two test posts shall be installed, for surface flowline, one at each end of crossing. It shall comprise of two cables, one monitoring and one drain cable, from flowline.

Note: Bond box shall be used for test posts under 5.6.3.4 to 5.6.3.6, 5.6.3.8, 5.6.3.9 and for other applications Big Fink Test post is adequate.

4.7 Reference Cells

The type of reference cell shall be selected based on the environment as per the following general guidelines:

Environment	Type of reference cell
Soil / water with chloride content less than 1000 ppm	Copper-copper sulphate
Soil / water with chloride content equal to more than 1000 ppm	Silver-silver chloride

The reference cells shall be provided with a moisture retention membrane.

The body of the reference cell shall be made of high impact ABS / Ceramic and shall be suitable for the application (buried / submerged).

4.8 ER Probes

Electrical Resistance (ER) probes shall be used for the monitoring of the corrosion rate of the structures.

The ER probe element shall be the same as that of the structure material. It shall be of heavy duty construction suitable for installation as per the stringent construction site requirement e.g. under the tank bottom. It shall be supplied with sufficient cable length so that cable can be routed to the junction box.

A portable Instrument, compatible with the ER probe, shall be supplied to read the Electrical Resistance / Corrosion rate of the ER probe.

4.9 Electrical Isolation

Wherever practical, the cathodically protected structures shall be electrically isolated from other structures for effective cathodic protection.

Based on the construction, either Isolation Joint or Isolating Flange shall be used.

4.9.1 Isolation joints

Monobloc Isolation joints shall be manufactured and tested as per COMPANY Engineering Standard.

In addition to this, Isolation Joint shall be tested for electrical resistance.

The electrical resistance across the joint shall be more than 1 mega Ohm (106 Ohm) measured at 1000 Volts DC in dry air.

IJ shall be provided with:

- 2 lugs for mounting the surge diverter (for the protection of IJ against lightning and surges).
- 4 independent lugs, welded at least 0,5m apart from each other to allow for testing of the IJ

4.9.2 Isolation Spools

Isolating spools may be manufactured out of non-conductive composite pipe material or as an internally coated or lined steel spool with isolating joints or flanges at both ends, depending on pipeline service, pressure and temperature.

4.9.3 Isolating Flange

Flange insulation kit shall comprise of insulating gasket, insulating sleeves and washers.

The type of the gasket (Raised Face or Full Face) shall be compatible with the flange.

The insulating materials shall be suitable as per the operating conditions like size, diameter, pressure, temperature and product.

The following materials are recommended for IF kits:

Gasket:

GRE or GRE with a metallic core. The metallic core requirements depend upon the pressure rating. Generally up to 300 class, gasket without steel core is sufficient. For 600 and higher class, gasket shall have a metallic core.

Sleeve:

GRE or Mylar shall be used. GRE is preferred as it is better than mylar in terms of strength. Both have excellent dielectric properties.

Washers:

GRE washers shall be used as it offers excellent resistance to crushing, cracking, breaking and thread pinch.

4.10 Deep Anodebed Materials

This section defines the material requirements for the deep anodebed components.

Deep anodebed shall comprise of MMO anodes installed in a cokebreeze column. Specifications of the anodes is covered under Impressed Current Anodes. Main components of the deep anode bed shall be as follows:

4.10.1 Casing

A combination of steel, PVC and steel casing shall be used for the deep anodebed.

The active column of the anodebed shall be housed in a steel casing. The casing shall extend 5m above the top of the coke breeze column to allow pumping of extra coke breeze in future (it could be used to reduce the anodebed resistance).

The internal as well as external surface of steel casing shall be uncoated. The diameter of the casing shall be 8". The bottom of the casing shall be covered with a bottom plate to prevent flow of mud / water into the casing.

The casing shall be supplied in 6m / 12m lengths. The casing pipes shall either be jointed using threaded couplers or individual pipes shall be welded.

8" PVC casing shall be used for non-active column of the deep anodebed. A special coupler shall be used to join the steel casing to PVC casing and PVC casing to steel casing. The PVC casing shall have male and female threads to facilitate jointing the pipes.

Top 6m of the casing shall be of steel. It will extend 1m above the grade level. The top of the casing shall be provided with a blind flange. Blind flange shall have a hole to facilitate exit of 1" vent pipe. Casing shall also have the provision for anode cable exit to anode junction box.

A 50 mm diameter steel pipe shall be provided in the top steel casing, approximately 300mm from top, to loop around anode tail cables and tie the polypropylene rope supporting the anodes.

Note: A well coated steel casing may be used for non-active column as an alternative to PVC casing.

4.10.2 Uncased deep anodebed

Uncased or open hole deep anodebed may be allowed in certain cases if the CONTRACTOR can ensure that all anodebed components are available at site at the time of drilling and anodebed installation can be completed immediately after drilling before the bore hole collapses.

The minimum diameter of the borehole shall be 8".

In this case a 12m PVC surface casing shall be used. The casing size shall be adequate to accommodate 8" drill bit.

The top of casing shall extend 1m above the grade level. The top shall be covered with a cover. A hole shall be provided in the cover to facilitate exit of 1" vent pipe. It shall also have the provision for anode cable exit to anode junction box.

A 50mm dia steel pipe shall be provided, approximately 300 mm from top, to loop around anode tail cables and tie the polypropylene rope supporting the anodes.

4.10.3 Water well as deep anodebed

Water wells, utilized to supply water during drilling operations, shall be modified as CP anodebed.

The water well will have 7” steel casing from top to bottom. It will have a 13 3/8” steel casing (0-12 m) that is used to facilitate drilling. The annulus space is filed with cement. A 24 feet stainless steel screen is provided at the bottom section of water well. The bottom of 7” casing will be covered by welding a circular plate or wooden plug.

7” casing shall be used as CP well casing and anodebed components shall be installed to use it as CP anodebed.

Note: Water well shall be drilled by others and same shall be handed over to CP contactor to use it as CP anodebed.

4.10.4 Carbonaceous Backfill material

Calcined Petroleum carbonaceous backfill (commonly referred as coke breeze) is used to lower the anode to earth resistance and provide a uniform column around the anode. The backfill shall have the following chemical composition:

Element	%age by weight
Fixed Carbon	99.3
Ash	0.6
Moisture	0.05
Volatile material	0.0

The backfill shall be dust free. The maximum particle size shall be 1.0mm. The specific gravity of the coke breeze shall be more than unity.

The maximum resistivity of the coke breeze shall be 0.1 Ohm-cms when lightly tamped.

It shall be supplied in heavy duty polyethylene waterproof bags.

Backfill shall be supplied with original test certificate issued by manufacturer.

4.10.5 Conductive Concrete (Carbonaceous Backfill material with Conductive Cement)

Conductive Concrete, comprising of high purity carbonaceous backfill and conductive cement, may be used as an alternative backfill material as it enhances the performance of the groundbed by reducing / stabilizing the anodebed resistance.

Conductive Concrete shall not be used for deep anodebeds with casing.

CONTRACTOR shall approach ADNOC Onshore / TC-P (ENG) for approval of Conductive Concrete for specific project (s).

4.10.6 Vent Pipe

Vent pipe shall be used to provide easy escape to the gases generated in the anodebed due to passage of CP current.

Vent pipe shall be made of 1” NB UPVC pipe. It shall have fine slots (0.3mm wide) in the wall to permit flow of gases generated in coke breeze column to the vent pipe. The slots should not be big to prevent ingress of cokebreeze particles into vent pipe. The slotted vent pipe shall be used for coke breeze column and shall extend 6 m above the coke breeze column.

The top section of vent pipe (top of casing to 6m above coke breeze column) can either be slotted or without slots.

Two 90° bends shall be provided at the top of vent pipe as it exits 8” PVC casing.

4.10.7 Anode Centralizer

Anode centralizers shall be provided to keep the anodes in the center of the coke breeze column.

These should not damage the coating of the anode.

4.10.8 Anodebed Headworks

A head work shall be constructed at the top of the anodebed. It shall serve the dual purpose of protecting the anodebed components and act as anodebed marker.

Wherever possible the anodebed, anode junction box and DC power source shall be erected at the same location.

The headworks shall cover the DC power source, anodebed and anode junction box. It shall basically comprise of a concrete foundation and a fence. The concrete foundation shall have the provision of cable entries.

Note: Refer ADNOC Onshore Standard drawings 30-99-62-0010-01 Sheets 23/80, 24/80 and 44/80 for deep anodebed component details.

4.11 Surge Diverter

The explosion proof surge diverter / spark gap shall be used for the protection of Isolation

Joints / Isolation Flange Kits against lightning surges and fault currents. It shall be installed across IJ / IF kits using the shortest possible cable length. It shall be supplied with 1.5m cable. The extra length of the cable shall be cut at the time of installation.

It shall have following specifications:

Lightning Impulse current (10/350 µs)	:	50 kA
Rated impulse spark over voltage	:	$\leq$ 2.5 kV
Housing	:	Die-cast zinc
Cable	:	1x 25mm^2 - 1.5m long

The spark gap shall be suitable for installation in hazardous areas.

4.12 Pin Brazing Material

Pin brazing material shall be compatible with pipeline material. The penetration of the brazing metal into the pipeline / structure shall not exceed 1mm. The hardness at the pin brazing location shall remain within the original pipeline requirement.

The pin brazing shall either be direct braze type or threaded (M10 size) type. For each cable connection a separate pin shall be used.

4.13 Welded Pad for Cable Connection

The welded pad shall comprise of a 50mm x 50mm metal plate. The plate shall be made of the same material as that of the pipeline. It shall have a welded M10 threaded stud at the center.

4.14 Encapsulation Materials

The encapsulation material shall be compatible with the coating of the pipeline / structure.

It shall be suitable for the operating temperature of the product being carried or stored by the protected structure.

Details of the encapsulation materials shall be submitted for approval by COMPANY.

Two part liquid epoxy or two part epoxy putty are recommended for cable joint encapsulation.

4.15 Solid State Polarization Cell or Polarization Cell Replacement

Solid state polarization cell (SSP) or Polarization Cell Replacement (PCR) shall be used to connect the pipeline / structure to earthing (plant earthing or zinc grounding cells / zinc ribbon anodes connected to the pipeline for AC mitigation). These prevent the flow of low voltage DC current (associated with CP system) to the earthing but allow discharge of high voltage DC / AC currents.

The technical details of the product shall be as under:

Parameter	Value / Description
Peak surge current at @ 8 / 20 µ sec	100 kAmps

AC Fault Current Capacity @ 50 Hz AC rms	9 kA / 5 kA / 3.5 kA
Voltage threshold	-3 / + 1 Volts
Steady State AC current @ 50 Hz rms	40 Amps
Enclosure	Stainless steel suitable for wall mounting / channel mounting
Enclosure Type	Weather proof or explosion proof as per the area classification
Cable termination	Copper terminal pads

The equipment shall be tested and approved by an international independent testing lab.

MANUFACTURER shall supply the type test certificate and original test report.

4.16 Polarization Coupon and Reed Switch

Buried coupons shall be used to monitor the "OFF" potential of the pipelines / structures without interrupting the DC power source.

The approximate exposed surface area of the coupon shall be as under:

3 LPE / PP coated pipelines - 1cm x 1cm

Uncoated structures - 7cms x 7cms

The coupon shall be fabricated from the same material as that of the pipeline / structure. The exposed surface of the coupon shall be uncoated.

Two nos. 1x10mm^2 Cu/XLPE/PVC red cables shall be attached to the coupon. The cable length shall be sufficient so that it can be routed to the test post without splicing.

The coupon shall be housed in a PVC box and the box shall be filled with epoxy.

A reed switch shall be used to operate the coupon. Reed switch shall be operated by a magnet. During the normal operations the reed switch shall be in closed position. The reed switch shall have a solid copper cable soldered to the contact and switch. The entire assembly shall be encased in epoxy.

The reed switch magnet shall be a permanent magnet which shall operate the switch from a distance of 5 mm or less. One magnet shall be supplied with each red switch.

4.17 Miscellaneous Items

This section defines the requirement of miscellaneous items that are needed to complete the installation, commissioning and operations of cathodic protection systems.

4.17.1 Cable markers

Cable markers shall be used for identification of cable route. Two types of cable route markers are used.

Concrete marker

These shall be made of concrete and the word "CP CABLE" shall be embossed on top of it.

It shall show the direction of cable.

The height of the marker shall be 500mm above the grade. Minimum 300mm of markers shall be embedded in the ground.

Pole mounted marker

Pole mounted marker post are recommended for the areas where concrete markers can be inundated by sand.

It shall comprise of 3" dia x 1650mm long support pipe. A 270mm x 150mm x 3mm thick MS plate shall be welded to the support pipe. A 250mm x 250mm x 6mm thick MS plate shall be welded at the bottom of the pipe.

Complete assembly shall be cleaned and painted bright yellow. Identification letters in black colour shall be stenciled on both sides of the plate.

"CP CABLE" shall be painted on the identification plate. It shall also show the direction of the cable.

4.17.2 Cable tiles

Cable tiles shall be made of solid polyethylene board. The minimum size shall be 150mm x 6mm x 1000mm. The word "CAUTION ELECTRIC CABLE BELOW" shall be printed on a contrasting colour background.

The tiles shall be predrilled so that these can be secured with self-locking plastic pegs. The pegs shall be supplied with tiles.

Alternatively concrete blocks shall be used as cable protection tiles.

4.17.3 Cable warning tape

Cable warning tape shall be yellow PVC. The minimum width of tape shall be 200mm and it shall be marked with “Danger Electric Cable”.

4.17.4 Cable Lugs

Cable lugs shall be made of tinned copper and of crimp compression type. These shall be correctly sized as per the cable size and the bolt to which the cable is to be terminated.

4.17.5 Cable Identification Tags

All ends of the cables shall be identified with permanent stainless steel cable tags. The cable tag shall clearly identify the equipment / purpose for which it is used.

The marking on the cable tags shall be as per the Project documents.

APPENDIX 2: DESIGN SPECIFICATIONS FOR CP REMOTE MONITORING AND CONTROL SYSTEM

1 GENERAL

Specification covers the requirements for design, procurement, installing and commissioning of the RMCS for cathodic protection system monitoring and control.

The Remote Monitoring equipment supplier/manufacturer shall have a minimum of 10 years' experience in manufacturing, supplying and installing remote monitoring systems for the energy industry as per NACE Standards and he shall be able to provide reference of all their customers in which they have installed their remote monitoring systems.

2 REMOTE MONITORING UNITS

3 REMOTE MONITORING FEATURES

The CP Remote Monitoring Facility shall be designed to do cathodic protection related monitoring and control. The main monitoring features shall be to:

Monitor the values of analog signals such as TR unit DC voltage, DC current, potential of reference electrodes, soil to pipe potential 'ON' and Instant 'OFF'.

Remote control of TR voltage setting (manual mode) and switch off the TR unit above the set output voltage.

Record monitored signals at programmable time intervals

Monitor and control the state of an external device ("ON/OFF")

Use GPS technology to for time-synchronized interruption of rectifier output

3.1 Monitoring

Cathodic Protection System Monitoring

Standard Cathodic protection parameters shall be monitored. The typical inputs for Cathodic protection monitoring shall be the rectifier output voltage, the rectifier output current and the structure to soil potential versus the permanent reference electrodes as per GASCO technical data sheets available with GASCO ENGINEERING & TECHNICAL SUPPORT DIVISION.

AC Power Monitoring

The presence of AC power before and after the circuit breaker inside the rectifier shall be monitored.

Generator Monitoring

At locations where generators are installed, the Remote Monitoring shall be able to monitor the signals specific to that site. Appropriate signal sensors shall be included with the Remote Monitoring as an option.

Temperature Monitoring

The CP Remote Monitoring Facility shall be able to monitor the temperature where typical sensing points shall be in the transformer of the rectifier and the body of the generator.

3.2 Control

Adjust Pipe to Soil Potential from Office Computer

An output shall be provided for auto-potential units to drive power switch (es) to turn and keep the rectifier output to “Manual Control” from “Automatic” and switch it back when required.

The power switch shall allow the operator to adjust TR output DC voltage continuously up or down to a desired potential. This feature is required if automatic control fails to regulate TR output or when reference cell fails to perform.

Rectifier ON/OFF control from Office Computer

An output shall be provided to drive a power switch to turn and keep the rectifier OFF for a programmable period of time. This feature shall allow the operator to complete depolarization testing.

Rectifier Interruption cycles (Current Interrupter)

The CP Remote Monitoring Facility shall be equipped with a remotely programmable current interrupter. The interrupter shall be synchronized from radio signals received from Global Positioning System (GPS) satellites. The maximum time deviation between two rectifiers being interrupted shall be 5 milliseconds. As well, an output shall be provided to synchronize portable interrupters to the Remote Monitoring interrupter.

3.3 Alarms and Call Back

Periodic Call Back

Periodically calling back an office computer to report operating parameters shall be featured. The time between each call shall be programmable from one call every 5 minutes (for test purposes) to 1 call per month (normally monthly readings). The office software shall be able to receive these calls, identify the calling unit and poll the required readings from the Remote Monitoring system.

Exception Call Back

The CP Remote Monitoring Facility shall call back an office computer to report if at least one of the monitored signals is outside set limits. It shall then report abnormal output current, voltage, temperature and pressure, if those are the signals being monitored.

Alarm Call Back

The CP Remote Monitoring Facility shall be able to call back an office computer to report AC power loss, and the restoration of AC power.

Interruption Call Back

The CP Remote Monitoring Facility shall be able to call back an office computer to report the start and the end of rectifier interruption.

3.4 Data Recording

Normal Recording

The CP Remote Monitoring Facility shall be programmable to record monitored signals at the programmed time intervals. Recording shall be done on selected inputs. The content of this memory shall then be transferred to the office computer. Should the memory become full before a transfer is requested, the memory full alarm shall automatically call the office computer to transfer the content of its memory.

Instant OFF Recording

The CP Remote Monitoring Facility shall be programmable to record Instant "OFF" potentials at a programmable time and frequency. When performing this type of recording, all Remote Monitoring systems that are programmed the same way shall interrupt their respective rectifier synchronized on the GPS interruption module to avoid influence from other rectifiers on the line. The maximum time delay between the interruptions of two systems shall be +/- 5 milliseconds. The potential shall be sampled after a programmable time after the rectifier is turned OFF.

4 REMOTE MONITORING HARDWARE

4.1 Packaging

The CP RMCS facility shall be packaged in a SS 316L enclosures. Degree of protection shall be IP 65. This type of designation shall provide corrosion and water protection to the electronic circuits. There shall be a flexible watertight conduit to connect to the rectifier that comes supplied with the unit. The rectifier monitoring wires, the rectifier interruption signal wires and the AC power shall be passed through the same conduit. The interruption power switch shall be installed inside the rectifier.

4.2 Power

The CP Remote Monitoring Facility shall be powered from 115 Volt AC or from 16 to 30 volts DC, enabling the use of existing power available at each site.

4.3 Back Up Power

The power shall use a rechargeable battery for backup. The battery shall be sized to insure that the CP Remote Monitoring Facility can generate alarm calls in case of power failure. The battery shall always be kept at optimum charge when power is available. In the event of power loss, the battery shall take over for a minimum of one hour to insure continuous operation.

When the battery voltage drops below a specified level, the whole system shall turn OFF. Normal operation shall resume only after the power is restored to a normal level.

In addition, the data memory shall also be equipped with an independent back up system to protect the integrity of the data recorded when no power is applied to the system.

4.4 Surge Protection

The CP Remote Monitoring Facility shall be protected against surges of up to 1 000 Volts @ 10 000 Amps coming from the analog inputs, AC power lines and telephone lines.

4.5 Analog Inputs

All of the analog input channels shall be sampled simultaneously, not sequentially. Inputs used for reference cell measurement shall have input impedance of at least 10 Mohms.

Each analog input shall be able to be remotely configured to any of the following ranges:

- ± 100 millivolts with 12 K ohm input impedance
- ± 10 Volts with 22 megohm input impedance
- to 0-100 Volts @ 22 MOhms
- to 0-350 Volts @ 22 MOhms

4.6 Digital Inputs

The status of at least two digital inputs from dry contacts or optically isolated devices shall be monitored.

4.7 Digital Outputs

There shall be one digital output to control the rectifier operation. This output shall be used to turn the rectifier OFF and back ON for depolarization and instant “OFF” readings (an independent circuit shall be used for interruption cycles). The same or independent circuit will be utilized for continuous control of TR unit in “Manual control mode”

4.8 Operating Environment

The CP Remote Monitoring Facility shall be able to operate in climatic conditions as per section 11.1 of these specifications.

4.9 Communication Interface

Local Communication

The CP Remote Monitoring Facility shall have an optically isolated RS232 port for local communication using a portable computer or hand held data logger. This local port shall provide access to all functions and settings of the Remote Monitoring system.

Remote Communication

The remote communication port shall be used for communicating with the Remote Monitoring system. The port shall be configured to interface with the different possible communication links. They shall specify and may be:

- Modem connected to a standard telephone line
- Modem connected to or inside a cellular telephone
- Radio modems
- Low Earth Orbiting Satellites (where available)
- Communications with the plant DCS.

The Remote Monitoring system shall be compatible and integrated with the existing system as practical. New desktop computer systems with the associated hardware and software shall be provided as needed for the new remote monitoring systems.

4.10 Memory

Data

The data memory shall be used to store historical information and the configuration of the Remote Monitoring system. It shall consist of a minimum of O Kbytes, to a maximum of 6 MB of CMOS static Random Access Memory with local battery backup.

System

The CP Remote Monitoring Facility shall be designed so that the operating software can be upgraded remotely by using the existing communication channel.

4.11 AC Rejection Frequency

The CP Remote Monitoring Facility shall be able to reject AC at the following frequencies:

- 50 Hz
- 60 Hz
- 400 Hz

5 REMOTE MONITORING SOFTWARE

5.1 General

The operating software shall be designed to run in the Microsoft Windows environment. It shall provide access to all the functions of the Remote Monitoring system. It shall have mapping software for a user-friendly interface.

5.2 Site Programming

This module shall provide basic data entry for an individual site. All information concerning the location, rectifier and monitored signals shall be entered through this module. The other modules of the program shall then use this basic information to call the CP Remote Monitoring Facility and generate reports.

5.3 Group Programming

Once the basic programming is complete, the grouping module shall have the capability to group any number of sites together. The communication module shall then automatically generate calls to all sites within a group and generate appropriate reports.

5.4 Communication

Calls to the Remote Monitoring Systems

The communication software shall allow communication to the Remote Monitoring system.

Standard Monitoring Calls

The communication module shall be able to call an individual or a group of Remote Monitoring systems and automatically retrieve the following information:

- Actual “ON” and Instant “OFF” readings
- Actual status of the digital inputs
- Alarm status
- Data recorded with the different data recording functions
- Status of the current interrupter
- Actual voltage and current.

All information retrieved during a communication shall be permanently archived for future reporting.

Interruption Programming Calls

When it is required to use the built in current interrupters, or TR to be put in “Manual control Mode” of the Remote Monitoring system, the software shall have the capability to:

- Set up the interruption parameters common to all rectifier systems being interrupted.
- Select the rectifiers to be interrupted or continuously varied.
- Automatically generate a call to program the interruption cycles for all selected rectifiers.
- Program the Remote Monitoring systems to automatically call back the office computer in case of interrupter malfunction at least once daily, until interruption cycles stop. The daily call shall be generated before the interruption cycles start. A screen and/or printed report showing the status of each CP Remote Monitoring Facility programmed for interruption is generated.

Depolarization Programming Calls

When it is required to perform a depolarization test, the software shall have the capability to:

- Set up the depolarization starting date time and duration.
- Set up the inputs used to record information during depolarization.
- Set up the acquisition speed during depolarization.
- Select the rectifiers to be de-energized.
- Automatically generate a call to program the depolarization for all selected rectifiers.
- Program the Remote Monitoring systems to automatically call back the office computer at the end of the depolarization test to transfer the data.
- Receive the call at the end of a depolarization test and ask the CP Remote Monitoring Facility to transfer the data.

Calls from the Remote Monitoring System

The software shall be able to receive calls from the Remote Monitoring system, identify the calling unit and the type of call.

If the call received is an alarm call, the information shall be routed to a section of the program handling faults in the system.

If the call received is a daily call while the interruption cycle is programmed, the information shall be routed to a global report for all rectifiers being interrupted.

If the call received is a normal periodic call, the information shall be routed to the main database handling all the historical information for the pipeline.

5.5 Reports

The software shall generate reports to satisfy required regulations. The reports shall include:

- A monthly report showing the readings from every system. The report shall highlight readings outside limits and systems, which did not call.
- A single page yearly report for each Remote Monitoring. This shall be used to show the monthly readings for each site.
- At any time, an exception report shall be available. This report shall show the Remote Monitoring systems, which called because of abnormal conditions, and the systems that should have called but did not.
- A screen and printed report shall be available when using current interruption. This report/screen shall clearly identify that the Remote Monitoring systems that are programmed for interruption are working properly during the whole period of operation.
- Report information shall be compatible with standard spreadsheet programs.

5.6 Graphs

The reports described in the previous section shall also available in a graphical form, on the screen and printer.