PETROBRAS	**TECHNICAL SPECIFICATION**	Nº: I-ET-3010.00-5267-750-P4X-002	
	CLIENT:	SHEET 1 of 17	
	JOB:	--	
	AREA:		
DDP-SRGE	TITLE: **TECHNICAL SPECIFICATION FOR GALVANIC ANODES**	INTERNAL	
		ESUP	

MICROSOFT WORD / V. 2016 / I-ET-3010.00-5267-750-P4X-002_C.DOCX

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL ISSUE
A	ITEM 5.4.2 REVIEWED
B	CHANGES ARE MARKED IN GREY
C	ITEM 4.4 CHANGED.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	MAR/10/20	DEZ/02/20	APR/06/21	OCT/14/22					
DESIGN	ESUP	ESUP	ESUP	ESUP					
EXECUTION	MARLON	CXO5	CXO5	CXO5					
CHECK	FERNANDORT	NTX1	NTX1	NTX1					
APPROVAL	LUCIANARM	UPDM	UPDM	UPDM					

SUMMARY

1. INTRODUCTION

This document aims to present the Petrobras Mandatory Requirements applicable to the Cathodic Protection Design for Offshore Production Unit, which shall be addressed by concerned parts during the Unit Design stages. Furthermore, this document will be a guide for future studies and analysis on the Executive Design, the Detailing, Construction, Installation, Operation and Demobilization Design of the Unit.

This Technical Specification determines the requirements for the design, assembly and pre-operation of cathodic protection systems for offshore Stationary Production Units (UEP), such as: Semisubmersible (SS) unit, Floating Production, Storage and Offloading (FPSO) units; Floating, Storage and Offloading (FSO) units, Ships and Fixed Platforms.

A specific document shall consider these orientations on the occasion of the documentation issuance for the Executive Design (or Detailed Design) execution.

Mandatory Requirement is the provision defined as the most adequate and which application shall be performed in compliance with this Guideline.

2. NORMATIVE REFERENCE

The following related documents are essential to the application of this guideline. For dated references, only mentioned editions shall be considered. For undated references, the most recent editions of such documents (amendments included) shall be considered.

- **DNVGL-RP-B101 -** Corrosion Protection of Floating Production and Storage Units;
- **DNVGL-RP-B401 -** Cathodic Protection Design;
- **DNVGL-CG-0288 -** Corrosion Protection of Ships;
- **IEC 60079** - Electrical apparatus for explosive atmospheres;
- **MIL-A 18001 K -** Anodes, Corrosion Preventive Zinc Flat Disc and Rod Shaped.

3. TERMS AND DEFINITIONS

The terms and definitions indicated below shall be adopted for the purpose of this Guideline:

- Coating Efficiency (E) – Fraction of the surface effectively protected by the anticorrosive coating in order to restrict the reduction of the protective current on a specified structural area.
- Cofferdam – Empty, unmanned and normally closed compartment placed below the water level in a vessel that allows the electric interconnection from the reference anodes and electrodes to their electric cables inside the vessel, restraining the entrance of sea water to its interior.
- CPS - Cathodic Protection System.
- Final Anode-Electrolyte Contact Resistance (R_i) – Anode-electrolyte contact resistance as the anode has its dimensions reduced in consequence of consumption through its life cycle.
- Final Current (I_f) - Current intensity needed for protection against a possible polarization of a structure at the end of the life cycle adopted for the cathodic protection system.
- Final Current Density (D_f) - Current intensity, by area unit, required for protection and possible repolarization of a certain structure at the end of its life cycle, adopted for the cathodic protection system.
- Final Current Produced by the Anode ($\bar{I}_f$) – Current intensity produced by an anode as the anode has its dimensions reduced in consequence of consumption through its life cycle.
- Final Efficiency (E_f) - Efficiency of the coating in at the end of the life cycle adopted for the CPS.
- Initial Anode-Electrolyte Contact Resistance (R_i) – Anode-Electrolyte resistance with anode in its initial dimensions.
- Initial Current (I_i) – Current intensity needed for polarization of a structure submitted to cathodic protection to adequate formation of the calco-magnesian layer.
- Initial Current Density (D_i) – Intensity of the current, by area unit, needed for polarization of a structure submitted to cathodic protection, with the adequate formation of the calcomagnesian scaling.
- Initial Current Produced by the Anode ($\bar{I}_i$) – Current intensity produced by an anode in its initial dimensions.

- Initial Efficiency (E_i) - Efficiency of the coating in at the beginning of the structure operation.
- Jacket – Structural part of a fixed platform ranging from the foundation to just above sea level and above which the deck and/or modules are installed.
- Location Tests – Prior operation CPS test performed at the offshore floating unit location.
- Mean Current (I_m) - Current intensity needed for keeping the polarization of a structure through the life cycle of the cathodic protection system.
- Mean Current Density (D_m) – Current intensity, by area unit, needed for keeping the polarization of a structure through the life cycle of the cathodic protection system.
- Mean Efficiency (E_m) – Efficiency of the coating in the middle of the life cycle adopted for the CPS.
- Mudmat – Wood or steel panel used to support a structure in the seabed. In the case of jackets, the support is temporary until the definitive piling is completed.
- Polarization Time – Time required for achieving to a stable electrochemical potential protection of a structure submitted to cathodic protection.
- Sea Chest – Opening made in the vessel hull for aspiration or discharge of sea water used in several services and systems on the vessel.
- Sea Tests – Tests performed to check the functioning of the offshore floating unit's CPS in a region close to the shipyard.
- Turret – Mooring structure from the vessel to the seabed, internally or externally incorporated to the vessel hull by one or more bearings, that allows the free rotation of the vessel around the axis of this structure, providing the alignment of the vessel with the result of the environmental efforts.
- Velocity Factor – Cathodic protection current correction factor due to the relative velocity between the electrolyte and the structure to be protected.
- Vessels – SS, FSO and FPSO units and ships are considered vessels.

4. DESIGN OVERALL CRITERIA

4.1. Cathodic Protection Types That Apply

4.1.1. To the turret and the inner parts of tanks and sea chests the galvanic current CPS shall be used.

4.1.2. The galvanic current CPS shall be adopted for jackets of fixed platfoms.

4.1.3. For retrofitting systems, the cathodic protection type may be changed, due to a technical and economic evaluation performed.

4.2. The design shall comply with safety premises, taking the offshore unit hazardous areas plan into account.

4.3. The life cycle adopted for the cathodic protection system shall comply with the provisions of the Table 1.

Table 1 – CPS Design Life Cycle

Structure	CPS Life Cycle
Vessel hull	The life cycle of the vessel, or time period between dockings, as defined by PETROBRAS.
Sea chest	The life cycle of the vessel, or the time period between dockings, as defined by PETROBRAS, unless there is adequate access to anodes replacement. In this case, the life cycle adopted for the design shall be at least 5 years.
Tank	The life cycle of the vessel, or time period between dockings, as defined by PETROBRAS.
Turret	The life cycle of the vessel, or time period between dockings, as defined by PETROBRAS.
Jacket	The life cycle of the Unit.

4.4. Cargo tanks in cargo area shall be provided with bottom anodes. The anodes must be installed as close as possible to the bottom plate of the tank, in order to provide protection even with small films of water. It is recommended that the anode be fixed to the profile web, with its face at 300 mm from the bottom plate.

4.5. All internal surface of produced Water Tanks, Off-spec oil Tanks, Ballast Tanks and Slop Tanks, shall be protected by anodes.

4.6. The potential range to be adopted as a cathodic protection criterion for carbon steel structures shall be from -800 mV to -1100 mV, measured to the silver/silver chloride

(Ag/AgCl sea water) reference electrode, or from +250 mV to -50 mV, measured to the zinc (Zn) reference electrode.

NOTE 1: The structures and/or accessories made of materials other than carbon steel may require potential limits different from the ones described above. A specific study, in this case, shall be considered (see item 4.6).

4.7. The detrimental effects of cathodic protection for different kinds of materials and for coating shall be taken into account, in accordance to DNVGL-RP-B401 (Item Detrimental Effects of CP).

4.8. In the sizing of fixed platforms CPS, all the submerged area of the jacket shall be considered, along with the following elements: piles (buried part including the inner area of the first 5 diameters, in which the end of the pile is opened and the external buried part), mudmat, lines, conductors, well coatings and further accessories that also have metallic contact with the jacket.

4.9. The Coating Breakdown Factors for Cathodic Protection Design from DNVGL-RP-B401 shall be fulfilled. It shall be considered that in this guideline, as in other PETROBRAS standards, the “Coating Efficiency” (E) parameter is adopted, while DNV adopts the “coating breakdown factor” (F) parameter. The relation between both parameters is the following:

$$E = 1 - F$$

4.10. The welded connections shall be performed by qualified welders and shall be approved by the classification society in accordance with the qualification welding procedure.

4.11. 4.12. The galvanic current cathodic protection system shall be tested as described in item 8.

5. GALVANIC CURRENT CATHODIC PROTECTION SYSTEM – DEFINITIVE SYSTEM

The definitive galvanic current cathodic protection system shall be in compliance with the requirements provided in the following items:

5.1. Areas to be Protected

The CPS shall be designed for cathodic protection of all submersed surface, as per item 4.3. For potable water tanks, the cathodic protection system is not applicable. In this case, anticorrosive protection shall be adopted based on the selection of materials and/or proper coating system.

5.2. Anodes

5.2.1. The cathodic protection system shall be sized based on the following current capacities:

Table 2 – Design project for galvanic anodes

Type of anode	**Anode[a] surface temperature °C**	**Submersed in sea water**	
		Ag/AgCl Potential mV	**Current capacity: A.h/Kg**
Aluminium	≤ 30	- 1050	2000
	60	- 1050	1500
High Temp Alloy	80	- 970	690
Zinc	≤ 30	- 1030	780
	> 30 to 50[b]		

[a] For temperatures between the established limits, current capacity can be interpolated.
[b] Zinc anodes temperature shall not exceed 50 ºC.

As a criterion for accepting current capacity based on short-time testing, the following table shall be adopted.

Table 3 – Short-time testing current capacity

Type of anode	Mean current capacity: A.h/Kg	Open circuit potential mV (Ag/AgCl)
Aluminium	2600[a]	- 1050
Zinc	780	- 1030

[a]Any value less than 2500 Ah/Kg obtained from the objects that underwent testing is unacceptable.

5.2.2. Possible correction to anode current capacity and protection current density, due to operation temperature, shall be according to PETROBRAS expertise or to DNVGL-RP-B401 and B101.

5.3. Design, Construction and Assembly Specific Criteria

5.3.1. Anodes made out of different materials or alloys shall not be used in the CPS design for protection of the same area.

5.3.2. Galvanic anodes utilization factor shall be in compliance with DNVGL-RP-B401.

5.3.3. For ballast tanks and oily water tanks, service factor shall be 100%.

5.3.4. Anodes can be provided with a steel support fitted to welding and compatible with the structure to be protected. Anodes core and the burned areas shall be treated and painted similarly to the rest of the vessel.

5.3.5. For bolted anodes, all nuts, washers and bolts shall made of a material resistant to the fluid, being at least a 316 stainless steel, considering the information stated in 4.7(detrimental effects). Anodes supports shall be welded, according to I-ET-3010.00-1200-955-P4X-001- WELDING.

5.3.6. The cargo tanks, oily water tanks and ballast tanks with explosive atmosphere may be protected using galvanic anodes of zinc or aluminum alloys, provided that the operating temperature does not exceed 50ºC.

5.3.7. If the operating temperature exceeds 50ºC but don´t exceeds 60ºC, anodes of aluminium alloy shall be used, provided that the product of the anode installation height (m) multiplied by its gross weight (Kgf) is less than 28kgf.m. Height shall be measure from the bottom of the tank up to the center of the anode.

5.3.8. If the operating temperature is equal or exceeds 60ºC, special anodes alloys for high temperature shall be used.

5.3.9. Sea chests shall be protected by galvanic anodes bolted to supports welded into the hull.

5.3.10. The electrical resistance between the anodes and the structure shall not exceed 0.1Ω.

5.3.11. As criteria for distribution of anodes, it shall be considered that each anode protects at maximum one area of $40m^2$.

5.3.12. For produced water and off-spec oil tanks, special anodes alloys for high temperature shall be used.

5.3.13. Ballast tanks adjacent to tanks with operational temperature equal or higher than 60°C shall be evaluated (case-by-case) regarding the necessity to use special anodes alloys for high temperature.

5.4. Design Parameters

5.4.1. Fixed Platforms

The following parameters shall be considered during the Cathodic Protection System (CPS) design of jacket and structures connected to it:

a) Resistivity of Electrolyte: 25Ω.cm or as per DNVGL-RP-B401 provided that the environment variables are known (temperature and salinity) and type of soil in case of buried anodes;

b) current density: as per initial, mean and final current density tables of the DNVGL-RP-B401 and B101 for environment conditions (climate region and depth);

c) coating efficiency: as per item 4.9;

d) velocity factor: as per Table 2.

5.4.2. Ballast Tank

The parameters to be considered during the Cathodic Protection System design shall be as follows:

a) Resistivity of electrolyte : 25 Ω.cm or as per DNVGL-RP-B401 provided that the environment variables are known (temperature and salinity);

b) current density: As per DNVGL-RP-B101;

c) coating efficiency: as per item 4.9;

5.4.3. Cargo Tanks and Oily Water Tanks

The parameters to be considered during the Cathodic Protection System design shall be as follows:

a) Resistivity of electrolyte : 25 Ω.cm or as per DNVGL-RP-B401 provided that the environment variables are known (temperature and salinity);

b) D_m: 60 mA/m2;

c) coating efficiency: as per item 4.9;

5.4.4. Sea chests, Turrets and Temporary Systems of Vessel's Hull.

The parameters to be considered in the Cathodic Protection System Design shall be as follows:

a) Resistivity of electrolyte : 25 Ω.cm or as per DNVGL-RP-B401 provided that the environment variables are known (temperature and salinity);

b) current density: as per initial, mean and final current density tables of the DNVGL-RP-B401 and B101 for environment conditions (climate region and depth);

c) coating efficiency: as per item 4.9;

d) velocity factor: as per Table 4.

Table 4 – Velocity Factor X Structure/Electrolyte Relative Velocity

Speed (m/s)	Velocity factor
0 to 1,5	1,0
1,5 to 3,5	1,1
> 3,5	1,2

5.5. Designing

5.5.1. The estimated life cycle values, coating breakdown factor, cathodic protection current density, electrical resistivity of electrolyte and velocity factor, which are defined in items 4.4, 4.9, and 5.4.4, shall be used for CPS designing.

5.5.2. Calculate the total initial current (I_i) from the following formula:

$$I_i = S_{sr}.D_i + S_{cr}.D_i(1 - E_i).f_v$$

Where:

I_i - total initial current, in A;

S_{sr} - surface area to be protected with no coating, in m^2;

S_{cr} - surface area to be protected with coating, in m^2;

D_i - initial current density, in A/m^2;

E_i - initial coating efficiency;

f_v - velocity factor.

5.5.3. Calculate the total mean current (I_m) from the following formula:

$$I_m = S_{sr}.D_m + S_{cr}.D_m(1 - E_m).f_v$$

Where:

I_m - total mean current, in A;

S_{sr} - surface area to be protected with no coating, in m^2;

S_{cr} - surface area to be protected with coating, in m^2;

D_m - mean current density, in A/m^2;

E_m - mean coating efficiency;

f_v - velocity factor.

5.5.4. Calculate the total final current (I_f) from the following formula:

$$I_f = S_{sr}.D_f + S_{cr}.D_f(1 - E_f).f_v$$

Where:

I_f - total final current, in A;

S_{sr} - surface area to be protected with no coating, in m^2;

S_{cr} - surface area to be protected with coating, in m^2;

D_f - final current density, in A/m^2;

E_f - final coating efficiency;

f_v - velocity factor.

5.5.5. Calculate the required anode weight (mass) from the following formula:

$$M = \frac{8760.I_m.V}{C.F_u}$$

Where:

M - Anode weight (mass) in Kg;

V - life cycle of Cathodic Protection System in years;

I_m - mean current, in A;

C - Current capacity in A.h/kg, as per 5.2.1;

F_u - Utilization factor, as per 5.3.2.

5.5.6. Select anodes of aluminum or zinc alloys Determine the minimum quantity of anodes (n) in order to find out the anode weight (mass) calculated as per 5.5.5, observing criteria for anode distribution defined in 5.3.10:

$$n = \frac{M}{M_{net}}$$

Where:

n - minimum quantity of anodes;

M - anode weight (mass) calculated as per 5.5.5, in kg;

M_{net} - net weight (mass) of the chosen anode, in kg.

5.5.7. Determine the initial current produced ($\bar{I}_i$) by the anode selected in 5.5.6, from the formula below:

$$\bar{I}i = \frac{\Delta E}{R_i}$$

Where:

$\bar{I}_i$ - initial current produced, in A;

ΔE - 0.25 V for submersed anodes and 0.15 V for buried anodes.

R_i - initial resistance of anode-electrolyte contact, in Ω.

5.5.8. The value of (R_i) for anodes of aluminum alloy or zinc alloy with square cross section is calculated from the following formula:

$$R_i = \frac{\rho}{2\pi . L_i}\left[\ln\left(\frac{4L_i}{r_i}\right) - 1\right]$$

Where:

R_i - initial resistance of anode-electrolyte contact, in Ω.

ρ - electrical resistivity of electrolyte, in Ω.m;

L_i - initial length of anode, in m;

r_i - initial equivalent radius of anode, in m.

NOTE: The value of (r_i) is calculated with the anode dimensions given by means of the following expression.:

$$\mathrm{r}_i = \frac{c_i}{2 \cdot \pi}$$

Where:

r_i - initial equivalent radius of anode, in m.

$C\mathrm{i}$ - perimeter of the initial cross section of the anode, in m.

5.5.9. The value of (R_i) for flat anodes of aluminum alloy or zinc alloy is calculated from the following formula:

$$R_i = \frac{\rho}{2.Le_i}$$

Where:

R_i - initial resistance of anode-electrolyte contact, in Ω.

ρ - electrical resistivity of electrolyte, in Ω.m;

Le_i - average between the final length and width of the anode, in m.

NOTE: This formula is used when the length of the anode is, at least, twice its width.

5.5.10. The initial current supplied to each anode ($\bar{I}_i$), calculated in 5.5.7, shall be compared to the total initial current calculated in item 5.5.2 (I_i), and shall match the following requirements:

$$n \cdot \bar{I}_i \geq I_i$$

5.5.11. Determine the final current produced ($\bar{I}_f$) by the anode selected in 6.5.6, from the following formula:

$$\overline{\mathrm{I}}_f = \frac{\Delta E}{R_f}$$

Where:

$\overline{\mathrm{I}}_f$ - final current produced, in A;

ΔE - 0.25 V for submersed anodes and 0.15 V for buried anodes.

R_f - final resistance of anode-electrolyte contact, in Ω.

5.5.12. The value of (R_f) for anodes of aluminum alloy or zinc alloy with square cross section is calculated from the following formula:

$$R_f = \frac{\rho}{2\pi . L_f}\left[\ln\left(\frac{4L_f}{r_f}\right) - 1\right]$$

Where:

R_f - final resistance of anode-electrolyte contact, in Ω.

ρ - Electrical resistivity of electrolyte, in Ω .m;

L_f - Final length of anode, in m;

r_f - final equivalent radius of anode, in m.

<u>NOTE:</u> The value of (Rf) is calculated with the reduced dimensions of the anodes at the end of the system's life cycle, considering a utilization factor of 90% and yet the reduction of length by 1% for each 10% of reduction in anode's volume. The reduced dimensions are obtained as follows:

a)Final length (L_f):

$$L_f = 0{,}910 \times L_i$$

b)Final equivalent radius (r_f):

$$r_f = \frac{c_f}{2\pi}$$

Where:

c_f - perimeter of the cross section at the end of the anode's life cycle, considering the final circular section, obtained through the sum of the volume of anode core and 10% of the initial volume of the anode alloy material, divided by the final length of the anode;

r_f - Final equivalent radius.

5.5.13. The value of (R_f) for flat anodes of aluminum alloy or zinc alloy is calculated from the following formula:

$$R_f = \frac{\rho}{Le_f}$$

Where:

R_f - final resistance of anode-electrolyte contact, in Ω.

ρ - electrical resistivity of electrolyte, in Ω.m;

Le_f - average between the final length and width of the anode, in m.

NOTE: This formula is used when the length of the anode is, at least, twice its width.

5.5.14. The final current supplied by anode ($\bar{I}_f$), calculated in 5.5.11, shall be compared to the total final current calculated in item 5.5.4 (I_f), and shall match the following requirements:

$$n \cdot \bar{I}_f \geq I_f$$

6. PROCEDURES FOR PRE-OPERATION OF GALVANIC CURRENT CATHODIC PROTECTION SYSTEM

6.1. After the anode installation services, a general inspection shall be performed for welds and electrical continuity between the anodes and the structure to be protected, considering the recommendations mentioned in this rule and also in the DNVGL-RP-B401 (item *Installation of Anodes).*

6.2. For jackets and vessel hull, after galvanic anode start-up, it is necessary waiting for the cathode polarization for at least 10 days (painted structures) and 60 days (bare structures). After that period, potential measurements shall be performed along the submersed structure for acknowledgment of satisfactory performance of the cathodic protection system.

6.3. All measured values shall be placed on the suitable range of protection as per 4.5 of this guidance and shall be registered in forms prepared for this purpose. After the initial measurements and delivery of the installations, the monitoring program of the cathodic protection system shall be submitted to the inspection routine defined by the classification societies or according to the intermediate inspections defined at the criteria of PETROBRAS.

7. DOCUMENT REQUIREMENTS

The documentations shall include at least the following information:

a) History information, design parameters and complete calculations, including formulas;

b) Drawings providing the general arrangement of anodes.