PETROBRAS | NI-2838 | REV. C | ENGLISH | 05 / 2020

Cathodic Protection for Floating / Fixed Marine Installations and Subsea Equipment

Procedure

This Standard replaces and cancels its previous revision.

CONTEC - Authoring Subcommittee provides guidance on the interpretation of this Standard when questions arise regarding its contents. The Department of PETROBRAS that uses this Standard is responsible for adopting and applying the clauses thereof.

Technical Requirement: A provision established as the most adequate and which shall be used strictly in accordance with this Standard. If a decision is taken not to follow the requirement ("non-conformity" to this Standard) it shall be based on well-founded economic and management reasons, and be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by imperative nature

Recommended Practice: A provision that may be adopted under the conditions of this Standard, but which admits (and draws attention to) the possibility of there being a more adequate alternative (not written in this Standard) to the particular application. The alternative adopted shall be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by verbs of a nonmandatory nature. It is indicated by the expression:
[Recommended Practice].

Copies of the registered "non-conformities" to this Standard that may contribute to the improvement thereof shall be submitted to the CONTEC – Authoring Subcommittee.

Proposed revisions to this Standard shall be submitted to the CONTEC - Authoring Subcommittee, indicating the alphanumeric identification and revision of the Standard, the section, subsection and enumerate to be revised, the proposed text, and technical/economic justification for revision. The proposals are evaluated during the work for alteration of this Standard.

CONTEC
Committee on Standardization Technique

SC - 15
Cathodic Protection

Introduction

PETROBRAS Technical Standards are prepared by Working Groups – WG (consisting specialized of Technical Collaborators from Company and its Subsidiaries), are commented by Company Units and its Subsidiaries, are approved by the Authoring Subcommittees - SCs (consisting of technicians from the same specialty, representing the various Company Units and its Subsidiaries), and ratified by the Executive Nucleus (consisting of representatives of the Company Units and its Subsidiaries). A PETROBRAS Technical Standard is subject to revision at any time by its Authoring Subcommittee and shall be reviewed every 5 years to be revalidated, revised or cancelled. PETROBRAS Technical Standards are prepared in accordance with PETROBRAS Technical Standard N-1. For complete information about PETROBRAS Technical Standards see PETROBRAS Technical Standards Catalog.

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FOREWORD

This Standard is the English version of PETROBRAS N-2838 REV. C 05/2020. In case of doubt, the Portuguese version, which is the valid document for all intents and purposes, shall be used.

1 Scope

1.1 This Standard establishes additional requirements for DNV-RP-B401 to be adopted in the design, manufacture, assembly, and pre-operation of cathodic protection systems for the structures listed below:

1.1.1 Fixed oil production platforms (Jackets).

1.1.2 Subsea equipment:

- ANM (Wet Christmas Tree);
- Manifolds;
- PLEM ("Pipeline End Manifold");
- PLET ("Pipeline End Terminal");
- SCM (Manifold Control System);
- PAB (Production Adapter Base).

NOTE: Submarine pipelines shall be designed according to PETROBRAS N-1935.

1.2 This Standard establishes additional requirements for DNV-RP-B101, to be adopted in the design, manufacture, assembly, and pre-operation of cathodic protection system for the structures listed below:

1.2.1 Floating marine installations such as:

- Semisubmersible platforms (SS);
- Floating Storage and Offloading (FSO);
- Floating, Production, Storage and Offloading (FPSO);
- Oil tankers;
- Buoys.

1.2.2 Ballast tanks, cargo, slop tanks, and spaces that can be immersed in sea or produced water.

1.3 Paragraphs of DNV-RP-B401 and DNV-RP-B101 not mentioned in this standard are considered entirely applicable.

1.4 This Standard applies to procedures initiated at the date of its edition.

1.5 This Standard contains Technical Requirements and Recommended Practices.

2 Normative References

The following documents are indispensable for the application of this document. For dated references, only the cited editions are applicable. For undated references, the most recent documents editions shall be applicable.

PETROBRAS NI-1935 - Design of Galvanic Cathodic Protection System - Subsea Pipeline.

PETROBRAS N-2064 - Emissão e Revisão de Documentos de Projeto.

PETROBRAS NI-2608 - Rectifiers for Cathodic Protection.

PETROBRAS N-2037 - Pintura de Equipamentos Submersos em Água do Mar.

ABNT NBR 9358 - Anodos de Liga de Zinco para Proteção Catódica.

ABNT NBR 10387 - Anodos de Liga de Alumínio para Proteção Catódica.

ABNT NBR 16294 - Anodos de Titânio com Óxidos de Metais Nobres.

ABNT NBR 16482 – Ensaios Não Destrutivos - Medição de Potencial Eletroquímico - Inspeção Subaquática.

DNV GL-RP-B101 - Corrosion Protection of Floating Production and Storage Units.

DNV GL-RP-B401 - Cathodic Protection Design.

3 Terms and Definitions

For this document, the terminology, symbols and characters regarding cathodic protection design parameters, contained in the DNV-RP-B401 shall be applied.

3.1 vessels
the semi-submersible platforms, jackets, ships, floating storage units, and floating production units are considered vessels

3.2
CPS
Cathodic Protection System

3.3
coating efficiency (E)
surface effectively protected by the anticorrosive coating that causes a percentage reduction of the protection current required to polarize the coated surface in relation to the bare surface

3.4
initial current
current demand required for polarization of a surface subjected to cathodic protection

3.5
mean current
current demand required to maintain the polarization of a surface over the life of the cathodic protection system

3.6
final current
current intensity required for the polarization of a surface through the life considering an established layer of limestone, Ca and Mg

3.7
cofferdam
watertight compartment installed below the water level of a vessel, which allows the electrical interconnection of the anodes and electrodes of reference to the electrical cables of the vessel, restricting the entry of seawater

3.8
velocity factor
correction factor due to the relative fastness between the electrolyte and the structure to be protected

3.9
turret
asymmetric structure anchored to the seabed, incorporated, internally or externally, to the hull of a vessel through one or more bearings, which allows the free rotation of the vessel around the axis of this structure, providing full alignment of the vessel

3.10
jacket
structural part of a fixed platform, from the seabed foundation to above the sea level, on which the deck and/or modules are installed

3.11
mud mat
wooden or steel panel, used to support a structure on the seabed. In the case of jackets, the support is provisional until the final anchoring system

3.12
ROV
remotely operated vehicle

3.13
sea chest
opening made in the hull below the flotation line, intended to supply and discard water used by the vessel

3.14
docking
scheduled stoppage of the vessel on a shipyard for inspection, maintenance, and repairs

3.15
service factor (for tanks)
percentage of the time that the tanks are filled, therefore anodes are submerged

4 General Considerations of Cathodic Protection Design

4.1 General

4.1.1 The choice of the type of cathodic protection system, impressed current or galvanic current, shall consider economic and technical aspects such as the life of the installation, dimensions, accessibility for maintenance, safety, reliability, availability, etc.

4.2 Electrochemical Potentials

4.2.1 The potential range to be adopted as a cathodic protection criterion for carbon steel structures shall be from -800 mV to -1150 mV, measured in relation to the silver-chloride-silver reference electrode (Ag/AgCl), or between +250 mV and -100 mV, measured in relation to the zinc reference electrode (Zn).

NOTE Martensitic, duplex and superduplex stainless steels may be subject to hydrogen embrittlement at potentials more negative than -800 mV (Ag/AgCl).

4.2.2 To convert the measurements of electrochemical potentials between Ag/AgCl and Zn electrodes, the following conversion (electrochemical potentials into mV) shall be adopted:

$$P_{Ag/AgCl} = P_{Zn} - 1050 \quad (1)$$

4.3 Anodes

4.3.1 Impresses current designs shall preferably use titanium inert anodes coated with mixed oxides of noble metals (MMO), according to ABNT NBR 16294. The use of titanium, niobium or tantalum platinized anodes or other types of anodes shall be submitted for Petrobras approval in advance.

4.3.2 Galvanic anodes made of aluminum or zinc alloys purchased in Brazil shall be specified according to ABNT NBR 10387 and ABNT NBR 9358, respectively.

4.3.3 Galvanic anodes made of aluminum or zinc alloys purchased outside Brazil shall be specified in accordance with DNV RP-B401.

4.3.4 It is recommended that galvanic anodes shall be made from the same material or alloy throughout the cathodic protection system. Any demand or need that differ from this recommendation, shall be submitted for Petrobras approval. **[Recommended Practice]**

4.3.5 For hanging installed inert anodes, the electric continuity cable shall not be part of the anode hanging system.

4.3.6 Flush-mounted anodes (plate type) shall be used in places subject to hydrodynamic stresses (marine currents), such as sea chest and vessel hulls. Stand-off anodes (long type) are recommended for other locations, such as jacket structures, tank interiors and subsea equipment. Other anode formats and applicable installation types can be specified according to the project.

4.4 Reference electrodes

Permanent reference electrodes shall be zinc type in accordance with ABNT NBR 9358 or DNV-RP-B401.

4.5 Rectifiers

4.5.1 The minimum conditions required for the supply, inspection, and testing of manual and automatic control rectifiers (air and oil cooled), used in cathodic protection systems of marine installations (vessels and platforms) shall follow PETROBRAS N-2608.

4.5.2 For each floating marine unit, it is recommended that the rectifiers have the same specifications. **[Recommended Practice]**

4.6 Vessels

4.6.1 Vessels with a total length greater than 150 m shall be provided with at least two impressed current systems, each one consisting of a rectifier and its anodes and reference electrodes, in compliance with the following requirements:

a) have at least two reference electrodes.
b) all reference electrodes shall be connected to the rectifier, to allow automatic control of the potential of the structure.
c) the rectifiers shall be installed in a sheltered and easily accessible place, protected from the marine atmosphere, mandatorily in non-hazardous area.

4.6.2 The entire submerged area shall be considered in the design of the CPS of vessels, considering the maximum draft, including structures that have electrical continuity between them and with the hull of the vessel, except for subsea pipelines which, whether metal-insulated or not, have independent CPS.

NOTE For non-isolated mooring chains and/or steel cables, an area corresponding to the 30-meters of its length shall be considered to drain current.

4.6.3 Anodes and reference electrodes shall be distributed on the submerged surfaces, installed at least 1 m below the minimum draught, as follows:

a) The anodes shall be located at the bow and stern to allow a uniform current distribution and potential throughout the hull of the vessel.
b) Anodes shall be installed at a minimum distance of 3 m from other hull accessories, such as sea chests, scuppers, sensors, etc.
c) Anodes and reference electrodes shall not be installed on the bulkhead of the load tanks.
d) The reference electrodes shall be installed at a minimum distance of 9 m from the inert anodes.

4.6.4 In the transport vessels, the propeller and rudder shall be protected with a higher concentration of anodes. It is recommended to install at least 20% to 30 % of the total of anodes at the region of stern. **[Recommended Practice]**

NOTE To ensure the metallic continuity of movable components, stainless steel or copper cables may be used, or individual anodes may be installed in each component.

4.6.5 Sea chests shall be protected by galvanic anodes screwed into welded hull supports.

4.6.6 Provisory CPS vessel hull shall be considered until the definitive CPS is installed and working.

4.6.7 Design shall meet safety premises, observing the hazardous areas plan of the facility.

4.7 Buoyance Modules

It shall be considered, in the CPS design of buoyance modules, all submerged area, including structures that have metallic continuity between its parts and installations, but excluding subsea pipelines that, metallically isolated or not, has independent CPS.

NOTE For non-isolated mooring chains and/or steel cables, an area corresponding to the 30-meters of its length shall be considered to drain current.

4.8 Jackets and Fixed Platforms Accessories

4.8.1 It shall be considered, when designing, all areas from parts that are submerged, buried or at the seabed transition zone.

4.8.2 The selected anodes shall be distributed in such a way as to protect an area of 30 m^2 to 60 m^2 per anode and proportionally to the demanded current of the submerged and buried parts.

4.8.3 Surface areas corresponding to well casings, piles and “mud mats” shall be considered buried.

4.8.4 Conductors and other accessories shall be electrically connected to the Jacket. Anodes designed to protect the conductors shall be positioned onto Jacket’s conductor frame, close to the conductor’s guide.

4.9 Subsea Equipment

4.9.1 Equipment composed of various demountable or recoverable components (e.g., manifold structure, control modules, wet Christmas tree, PAB, etc.), CPS design shall be performed for each part, individually.

NOTE CPS design of subsea pipelines, connected to equipment, shall be performed apart, although usually these structures have metallic continuity with each other.

4.9.2 Total current demand of complex structures, composed of dissimilar metals, shall be calculated as a sum of individual current demand for each material (carbon steel, stainless steel, nickel-plated steel, etc.). In special cases, numerical simulation software may be required to properly evaluate the current distribution.

4.9.3 Anodes distribution shall be as uniform as possible, without interfering in the equipment operation.

4.9.4 Initial, mean, and final current densities of components heated by internal fluids shall be increased by 1mA/m^2 for each degree Celsius of equipment external surface above the environmental

temperature. Internal fluid temperature may be used, conservatively, external surface temperature is unknown.

NOTE Consider the following ambient temperatures: 18°C for water depths up to 100 m, 12°C for water depths between 100 m and 300 m, 4°C for water depths greater than 300 m.

4.9.5 Anodes shall be installed inside unsealed closed compartments, with an opening for anodes corrosion products exit.

4.9.6 Painting for subsea equipment shall be in accordance with DNV-RP-B401 and PETROBRAS N-2037.

4.10 Tanks

4.10.1 The use of impressed current system for internal protection of tanks containing explosive atmosphere (load, “slop”, fuel, etc.) is not allowed.

4.10.2 Tanks with galvanic protection shall be protected only by aluminum alloy or zinc alloy anodes. Magnesium alloy anodes shall not be used.

4.10.3 Traditional zinc alloy anodes shall not be used in tanks with operational temperature higher than 50 °C. For temperatures between 50°C and 80°C, aluminum alloy anodes or special zinc alloy anodes for high temperature, purchased from suppliers qualified by PETROBRAS, shall be used.

4.10.4 Aluminum alloy anodes shall not be used in tanks with explosive atmosphere if the product of the height (m) of the anode installation by its gross weight (kgf) exceeds 28 kgf.m. The height shall be measured from the bottom of the tank to the anode center.

4.10.5 Cargo tanks for petroleum storage with possibility of water concentration shall be equipped with sacrificial anodes at the bottom. Tanks that store only petroleum products do not require cathodic protection.

4.10.6 Cathodic protection is not applicable in case of potable water storage tanks. In this case, anticorrosion protection system shall be based on material selection and/or due coating system with a potability certificate.

4.10.7 For ballast tanks, the distribution of anodes shall consider the higher current density at the bottom of the tanks. Ballast tanks near to a heated tank shall have a higher concentration of anodes in adjacent bulk scales.

4.10.8 For a tank storing a fluid different of that which it was designed for, it is recommended a thorough analysis of anodes and internal coating system compatibility with the new storage condition. [**Recommended Practice**].

4.11 Retrofit

4.11.1 Criteria adopted by PETROBRAS for evaluation of CPS retrofit project are:

a) Ease of installation, operation, and maintenance.

b) System robustness.
c) System layout resistant to mechanical damage (interference with other vessels, dropped objects, waves, sea current, etc.).
d) Quality of the materials to be employed.
e) Compatibility of the materials to be employed.
f) Direct and indirect costs of implementing the system.

5 Design Parameters

5.1 Current Capacity (Galvanic Anodes)

5.1.1 Galvanic anodes CPS shall be designed considering the following design values:

Table 1 – Design values for galvanic anodes

Anode type	Anode Surface Temperature (Note 1) ºC	Immersed in seawater		Buried in seawater sediments	
		Potential Ag/AgCl mv	Electrochemical capacity A.h/Kg	Potential Ag/AgCl mv	Electrochemical capacity A.h/Kg
Aluminum	≤ 30	- 1050	2000	- 1000	1500
	60	- 1050	1500	- 1000	800
	80 (Note 2)	- 1000	900	- 1000	400
Zinc	≤ 30	- 1030	780	- 980	750
	> 50 to 30 a (Note 3)			- 980	580
NOTE 1 For temperatures between limits stated, the electrochemical capacity shall be interpolated. NOTE 2 The temperature of aluminum anodes shall not exceed 80 °C. NOTE 3 The temperature of zinc anodes shall not exceed 50 ºC.					

5.1.2 Any correction of anode electrochemical capacity and of current densities, due to the operational temperature, shall be in accordance with PETROBRAS' previous experience or DNV-RP-B401 and DNV-RP-B101.

5.2 Coating Efficiency (E)

5.2.1 DNV-RP-B401 and DNV-RP-B101 shall be followed for the item "Coating Breakdown Factors for CP Design". It shall be considered that, in technical literature, sometimes the parameter "coating efficiency" (E) is used, while DNV adopts the "coating breakdown factor" (F), and that they have the following relationship:

$$E = 1 - F \quad (2)$$

5.2.2 Cargo ships' hulls, due to operational and environmental characteristics, with higher likely to coating damage, it shall be considered a mean breakdown factor of 0.2 and a final breakdown factor of 0.3 for the period between dockings.

5.3 Design Life

5.3.1 Impressed current CPS design life for vessels' hulls shall cover the vessel design life, in accordance with PETROBRAS' criteria.

5.3.2 Galvanic anodes CPS design life shall comply with the requirements from Table 2.

Table 2 – Galvanic Anodes CPS' Design Life

Installation	Adopted time for SPC design
Buoyance modules	Period between dockings.
Sea chests	Vessel design life or period between docking or class inspection schedule, as defined by PETROBRAS. If there is adequate access for the replacement of the anodes, a maximum period of 5 years may be adopted as a design life.
Tanks	Vessel design life or period between dockings or inspection/maintenance plan, as defined by PETROBRAS.
Turret	Vessel design life or period between dockings, as defined by PETROBRAS.
Jacket	Unity design life or as defined by PETROBRAS.
Hulls of vessels	Vessel design life or period between docking, as defined by PETROBRAS.
Subsea equipment	Equipment design life, also considering the period between installation and start of operation.

5.4 Velocity Factor

5.4.1 For vessels' hulls current demand calculation an additional parameter as a function of relative velocity between electrolyte and structure shall be considered.

5.4.2 Velocity factor as mentioned in DNVRP-B401, section 3.14.8, shall be employed as a compensation factor. Cathodic protection demand current shall be multiplied by this factor, which ranges from 1.25 to 1.5.

5.5 Current Densities (mA/m²)

Values for the current densities varies in accordance with following parameters: type of structure to be protected, coating system, water temperature and depth at installation point. Such values shall be defined in accordance with Appendix A of DNV-RP-B401 or Appendix B of DNV-RP-B101.

5.6 Service Factor (for Tanks)

For ballast and drainage tanks on production platforms, the service factor shall be 100 %. For ballast and slop tanks on transport vessels, the service factor shall be 50 %.

6 Design Calculations

6.1 General

6.1.1 Impressed or galvanic current anodes shall be distributed according to the criteria of the protection area and previous knowledge from other designs.

6.1. 2 It is recommended to use numerical simulation software to determine the anodes distribution to ensure an equal current distribution at the structure, and to confirm the absence of electrochemical potentials harmful to the installation. [**Recommended Practice].**

6.2 Impressed Current System

6.2.1 The calculations shall follow the guidelines of DNV-RP-B101, complemented by this PETROBRAS Standard.

6.2.2 The higher current calculated between the initial, mean, and final currents shall be used to determine the number of anodes and rectifiers.

6.2.3 The voltage and current ratings of the rectifier shall be equal to or greater than the anode ratings.

6.2.4 The electrical cables shall be adequate to the anode drained current.

6.3 Galvanic Current System

6.3.1 The calculation procedures follow the guidelines of the DNV-RP-B401 or DNV-RP-B101, complying with this PETROBRAS Standard.

6.3.2 The initial dimensions of the anodes shall be such that each anode is capable of delivery at least the initial current demand of submerged and buried areas.

6.3.3 With the final dimensions (end of life), each anode shall be able to delivery at least the final current demand of submerged and buried areas.

7 Anode Manufacturing, Inspection, Receiving and Storage

7.1 The guidelines from section 8 of DNV-RP-B401 shall be followed.

7.2 The short-term test described in Appendix B of DNV-RP-B401 shall always be used for quality control of galvanic anodes.

7.3 The acquire and storage of anodes shall meet the following criteria:

a) the acquiring entity shall compare the received material with the Material Purchase Order (MPO), including the anodes documentation.
b) on acquire, the anodes shall be free of damage.
c) anodes shall be stored in clean, supported on wood pallets preventing contact with the ground. The maximum stacking of anodes allowed is five units.
d) anodes shall be handled carefully, avoiding shock, cracks, smashing or damages in general.

8 System Installation

8.1 General

8.1.1 The guidelines of section 9 of DNV-RP-B401 shall be followed.

8.1.2 The distribution of anodes on the structures shall be in accordance with design and the documentation shall be updated for "as constructed" revision after.

8.2 Galvanic Current System

8.2.1 Anodes shall be installed by welding or fastening in the structures. Fastening shall use AISI 316 bolts and nuts.

NOTE 1 Welding shall be executed by qualified welders and shall be approved by a classification society where applicable, in accordance with qualified welding procedures.
NOTE 2 In cases where metal continuity is guaranteed by means of fastening, serrated washers shall be used.

8.2.2 Existing coating shall be removed for anode installation and repaired after according to original.

8.2.3 The metallic continuity between the anodes and the structure shall be tested after installation and the resistance shall be less than 0.1 Ω, excluding the resistance of the multimeter cable.

NOTE In moving parts with no anode, metallic continuity shall be provided by installation of stranded cable (typically insulated copper cables).

8.2.4 Anodes for Jacket platform shall be installed before lifting each panel.

8.3 Impressed Current Systems

8.3.1 The surrounding area and under inert anodes shall be protected with an insulating coating to provide shielding effect. The protected area shall extent at least 2 m radius around the anode and shall follow manufacturer application recommendations.

NOTE If there is any metal structure or accessories installed within a 2 m radius of the anode, it shall be properly coated.

8.3.2 Inert anodes and reference electrodes shall be provided with a cable or rod to allow connection to the electrical cable of the rectifier. The penetration shall be through a cofferdam.

8.3.3 The installation of the electric cable of anodes and reference electrodes externally to the hull shall be avoided, except in retrofit projects with previous Petrobras approval.

8.4 Retrofit of Cathodic Protection Systems

8.4.1 Hanging anodes or reference electrodes may be used in retrofit system design.

8.4.2 Installation of hanging anodes or reference electrodes shall be adequate to prevent damage during lifetime.

8.4.3 Hanging anodes and reference electrodes should be installed accordingly to minimize installation loads and water induced movements. **[Recommended Practice]**.

9 Commissioning

9.1 Generalities

The voltmeters and reference electrodes used in the measurements of the electrochemical potential shall be calibrated according to the requirements of ABNT NBR 16482.

9.2 Galvanic current systems

9.2.1 After anode installation services, a general inspection of the welds shall be carried out and the electrical continuity between anodes and the structure to be protected shall be guaranteed, following the recommendations contained in this Standard and in clause 9 of the DNV-RP-B401.

9.2.2 With the start of operation of the galvanic anodes, at least 14 days shall be held for the metal polarization. Potential measurements shall be carried out throughout the submerged structure using shallow diving services or ROV where necessary.

9.2.3 The measured electrochemical potential shall be situated inside the protection range according to 4.2 of this Standard and registered in forms drawn up for this purpose. After the delivery of the facilities, the galvanic cathodic protection system monitoring program shall follow the inspection routine defined by the classification societies or PETROBRAS' discretion.

9.2.4 Inside tanks, when it is not possible to perform potential measurements, it is recommended to perform visual inspections of the anodes and wall thickness measurements to control the effectiveness of the CPS.

9.3 Impressed current systems

9.3.1 Commissioning shall be divided into two stages: tests at the shipyard (dry) and at sea. The results shall be properly recorded.9.3.2 The system shall be adjusted so that the electrochemical potential is within the proper protection range in accordance with 4.2 of this Standard and all system parameters shall be recorded in forms drawn up for this purpose. 9.3.3 Measurements of the electrochemical potential along the periphery of the hull shall be performed with a portable reference electrode of Ag/AgCl or Zn, complemented by the readings obtained in the fixed reference electrodes of the vessel for comparison.

NOTE 1 The portable reference electrode shall be positioned approximately halfway through the side of the vessel, as close as possible to the structure to be measured, limited to 5 m.
NOTE 2 Measuring points with portable electrode shall be mapped as a reference for future inspections.

9.3.4 It is recommended to identify the measuring points with stainless steel plates, numbered sequentially and fixed along the marine unit, near the measure points with the portable electrode. This procedure also facilitates the connection of the positive tip of the digital voltmeter in the structure **[Recommended Practice]**.

9.4 Tests on the shipyard (dry)

9.4.1 The CPS shall be subject to component checks.

9.4.2 Component checks:

a) rectifier: electric power and polarity of the output: positive pole connected to the anodes and the negative pole connected to the cathode (structure).
b) electrical cables: metallic continuity of the anode, cathode, and electrode cables.
c) electrical insulation between anodes and reference electrodes in relation to the cathode (structure).
d) watertightness of the cofferdam.
e) grounding of the rudder and propeller shaft.

9.5 Tests on the sea

9.5.1 The CPS shall be subjected to functional testing, like operating conditions.

9.5.2 When contacting the sea, the CPS shall be energized, and the following parameters shall be checked:

a) voltage and current power (AC).
b) voltage and current output (DC).
c) operation of the instruments and tests of the alarms of the panel.
d) maximum current of each anode.
e) electrochemical potential in fixed reference electrodes.
f) automatic/manual mode switching.
g) "measured potential x voltage and output current" response curves.
h) performance of the automatic adjustment control as function of the vessel's draught.

9.5.3 The parameters described in 9.5.2 shall be monitored during the polarization process of the structure, for a minimum period of 10 days.

10 Operation and maintenance

10.1 Generalities

10.1.1 Operation and maintenance shall ensure that the CPS continues to operate properly and that the structure remains corrosion-free through its service life.

10.1.2 A plan for the inspection and maintenance of cathodic protection facilities shall be drawn up by the maritime unit team, including and not limited to visual and dimensional inspection, potential measurements, equipment adjustments, replacement of system elements.

10.1.3 The set of points to be inspected and measured may be reassessed at each inspection depending on the new scenario of anode wear and measured potential values, historic of failures, amount and severity of corrosion, CPS service life, among other information.

NOTE Any areas with underprotection, overprotection or the presence of electrical interference with other structures due to undesired connection to the protected structure shall be recorded and treated immediately.

10.2 Galvanic systems

10.2.1 Potential measurements shall be carried out according to the inspection plan defined by PETROBRAS or according to the periodicity defined by the class of the vessel.

10.2.2 Depending on the type of structure and location of anodes, a visual inspection with a diver or ROV can be carried out to verify the consumption of the anodes, possible physical damage, marine encrustation and the status of welds or connections.

10.2.3 The measurement of electrochemical potential shall be prioritized in places considered critical, such as regions with kneading, corrosion or coating wear, weld cords, close to anodes with severe or irregular consumption, and those that have already been consumed.

10.2.4 Perform electrochemical potential measurements in sea chests at three different locations in each of them.

10.3 Impressed current systems

10.3.1 The impressed current system shall have an indicator informing the “on” status, as well as informing any inactivity.

10.3.2 The following items shall be registered within a maximum interval of 15 days:

a) total current and voltage rectifier output.
b) hull potential related to fixed reference electrodes.
c) Individual current of each anode.

10.3.3 Fixed reference electrodes shall be calibrated at regular intervals not exceeding one year, comparing the measured potential with the potential of a newly calibrated portable reference electrode. The two electrodes shall be positioned as close as possible to each other.

10.3.4 Detailed potential measurements of the entire structure using a portable reference electrode shall be carried out every three months, following the maintenance plan, or after repairs to the cathodic protection system. The measurement of electrochemical potential shall be prioritized in places considered critical, such as regions with kneading, corrosion or coating wear, weld cords, close to inert anodes and adjacent to the fixed reference electrodes.

10.3.5 Maintenance of the inert anodes or fixed reference electrodes shall be carried out when faults are detected. The following aspects shall be evaluated:

a) continuity and fixation of the electric cables.
b) fixation of the anode/electrode to its support and the hull.
c) coating integrity of the anode and its dielectric layer.
d) cofferdam integrity.
e) presence of marine encrustation.

10.3.6 Verification and inspection of electrical insulation joints of structures not attached to the hull, and their operating condition, where applicable, shall be performed.

10.4 Docking

10.4.1 Galvanic anodes shall be inspected, and those with severe consumption or those that no longer last for another operation campaign shall be replaced.

10.4.2 For impressed current systems, the dielectric resistance between anodes and reference electrodes and the hull of the vessel shall be measured and shall exceed 1MΩ.

10.4.3 During the dieletric resistance measurement, the periphery of the reference anodes and electrodes shall be cleaned to avoid electrolyte continuity due to the formation of salt deposits.

11 Documentation

11.1 Design documents shall comply with PETROBRAS N-2064.

11.2 All information relevant to the cathodic protection system shall be recorded, including design, manufacturing, installation, commissioning, operating procedures, inspection, and maintenance of the system.

11.3 The "as-built" documentation shall reflect any changes to the design specification.

11.4 The following data shall be kept for reference and permanently updated, where applicable:

a) design premises, including the useful life, the characteristics of the aqueous medium, the protection criteria considered, the current density requirements, the calculated values of the output current of the anodes.
b) number of anodes, dimensions, mass, specification, alloy composition, consumption rate, as well as manufacturer references.
c) disposal of the anodes and the method of fixation.
d) number, type, and arrangement of the reference electrodes.
e) distribution of rectifiers.
f) commissioning results, including test results after turning on each cathodic protection system, to assess whether it meets the design criteria.
g) inspection and periodic maintenance reports, to monitor the changes in the state of the protection potential of the metal structure.