eni spa

COMPANY SPECIFICATION

CATHODIC PROTECTION SYSTEM FOR ABOVEGROUND STORAGE TANK

20301.ENG.COR.STD

Rev. 02 – October 2017

ABSTRACT	The purpose of this Company Specification is to set minimum requirements and recommendations for the design and implementation of cathodic protection systems of the external surfaces of aboveground storage steel tank bottoms and the internal surfaces of aboveground storage steel tank

02	October 2017	General revision of international normative and company references	Lucia Torri	Tiziana Cheldi	Lorenzo Cambiaso
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REVISION TRACKING

Rev. 00 17 pages
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Rev. 01 25 pages
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General revision

The present document incorporates and substitutes the following Company Standard ENI:

- 20302.VAR.COR.PRG "Sistema di protezione catodica ad anodi galvanici per superfici interne di serbatoi ed apparecchiature",
- 20303.VAR.COR.PRG "Sistema di protezione catodica a corrente impressa per le superfici interne di serbatoi contenenti acqua dolce".

Rev. 02 28 pages

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General revision of international normative and company references

INFORMATION REQUEST

Eni personnel can access company standard repository at:
http://wwweandp.eni.it/TSServices/ITEM/Standards-/Normalizat/Documents-/index.asp

External user shall refer to the Project Engineer Manager.

For information about the content of this standard, please refer to persons mentioned on first page or to Company Standard Team (mbxc&st@eni.com).

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1 SCOPE AND GENERAL INFORMATION

1.1 PURPOSE AND SCOPE

The purpose of this Company Specification is to set minimum requirements and recommendations for the design and implementation of:

- cathodic protection systems of the external surfaces of aboveground storage steel tank bottoms in contact with tank foundation;
- cathodic protection systems of the internal surfaces of aboveground storage steel tank in contact with fire fighting water, sea and brackish water, service water and potable water and crude oil or hydrocarbons with water phase at the bottom.

The Supplier of the cathodic protection systems shall be responsible for complying with the requirements and quality levels specified in this Company Specification.

1.2 DISTRIBUTION AND INTENDED AUDIENCE

This document is intended for use during projects phase and can be shared or distributed to Contractor and supplier

1.3 REFERENCES DOCUMENTS AND NORMATIVES

The latest edition of each publication shall generally be used, together with any amendments/supplements/revisions thereto, however new revisions/updates during an activity or project will not be considered unless there are associated safety/environmental impacts.

	Ref. Code	Title
01	bp dev-dms 001	DMS Best Practice – Acronyms and Definitions
02	EN 12499	Internal cathodic protection of metallic structures
03	EN 12954	Cathodic Protection of Buried or Immersed Metallic Structure - General principles and Application for Pipelines
04	EN 13509	Cathodic protection measurements techniques.
05	EN 14505	Cathodic protection of complex structures
06	EN 15257	Cathodic protection. Competence levels and certification of cathodic protection personnel
07	API 651	Cathodic protection of aboveground petroleum storage tanks
08	NACE RP0193	External cathodic protection of on-grade carbon steel storage tank bottoms
09	NACE SP0196	Galvanic anode cathodic protection of internal submerged surfaces of carbon steel water storage tanks.
10	NACE SP0388	Impressed current cathodic protection of internal submerged surfaces of carbon steel water storage tanks
11	NACE SP0575	Internal cathodic protection systems in oil treating vessels.
12	20309.ENG.COR.STD	Cathodic protection of buried structures in plant facilities.
13	27589.ENG.COR.STD	Guidelines for design and construction of cathodic protection systems

14	27964.ENG.COR.STD	Galvanic anode groundbed for cathodic protection systems of buried metallic structures
15	20305.ENG.COR.STD	Anodi a corrente impressa per strutture interrate
16	05019.ENG.COR.STD	Dispersori per sistemi di protezione catodica a corrente impressa
17	20000.ENG.CPI.STD	Protective Coating, galvanising and metallising for internal and external surfaces of offshore and onshore structures and related components

1.4 TERMS AND DEFINITIONS

1.4.1 General Definitions

The Company Standards shall comply with the use of the Company Terminology [Ref. 01]. All acronyms and abbreviations used in the document are summarized in section 1.4.2.

i. The Company is Eni SpA;
ii. The word **shall** is used to indicate that a provision is mandatory;
iii. The word **should** is used to indicate that a provision is not mandatory, but recommended as good practice.

1.4.2 Specific Terms, Definitions, Acronyms and Abbreviations [Ref. 01].

For the purpose of this specification the following terms and definitions apply.

Anaerobic	Lacking free oxygen.
Anode backfill	Material with a low resistivity, which may be moisture-retaining, immediately surrounding a buried anode for the purpose of decreasing the effective resistance of the anode to the electrolyte.
Corrosion Potential	Potential of a freely corroding metal with respect of a reference electrode in a given corrosion system.
Current capacity	The current capacity is the total amount of electricity that is produced when one kilogram of anode Material is consumed. The current capacity is expressed in Ampere-hours per kilogram (Ah/kg).
Current density	The current per unit area flowing to or from a metallic surface.
Electrical isolation	The condition of being electrically separated from other metallic structures or the environment.
Electrolyte	A chemical substance containing ions that migrate in an electric field. For the purposes of this recommended practice, electrolyte refers to the soil or liquid adjacent to and in contact with the bottom of an aboveground petroleum storage tank, including the moisture and other chemicals contained therein.

Foreign structure	Any metallic structure that is not intend as a part of a system under cathodic protection system.
IR drop	voltage developed across a resistance, or resistive path, in accordance with Ohm's Law.
Lining	Coating applied to the internal surfces of the tank, also mentioned as Internal Coating.
Membrane	A thin, continuous sheet of nonconductive synthetic material used to contain and/or separate two different environments.
Pad	The material immediately adjacent to the exterior steel bottom of an aboveground storage tank.
Polarisation	Change of potential of a metal surface caused by the application of an external electrical current.
Reference electrode	An electrode whose open-circuit potential is constant under similar conditions of measurement.
Utilization factor	Fraction of the anodic material weight of a galvanic anode that can be consumed before the anode ceases to provide the minimum required current output.

Ag/AgCl	(-)	Silver/Silver chloride electrode
Cu/CuSO4 sat	(-)	Copper/Copper sulphate electrode
CP	(-)	Cathodic Protection
DC	(A)	Direct Current
Eprot	V	Protection potential
PVC	(-)	Polyvinyl chloride
HEPR/PVC	(-)	hard grade ethylene propylene rubber / polyvinyl chloride
XLPE/PVC	(-)	cross-linked polyethylene / polyvinyl chloride

1.5 ORDER OF PRECEDENCE

In conjunction with this specification, the codes, standards and regulations listed in section 1.3 shall be applicable. Reference to any Standard or Code shall mean the latest edition of that Standard or Code including addenda, supplements or revisions, unless otherwise stated in this document.

The order of precedence shall be as follows: (descending order)

i. Local Regulations of the Country where the equipment is installed;
ii. Project Specifications and Data Sheets;
iii. Company General Specifications;
iv. International Codes & Standards

International Standards are at the lower level of hierarchy, their contents, assumed as reference, is developed and detailed within the Company Specifications considering the specific application and the area of business in which Eni SpA is operating. On top of those there are the Local Regulations, the Project Specifications than the Company Specifications. Any applicable local mandatory rule prevails on this specification. Should there be a perceived conflict between this standard and other referenced standards, or lack of clear definition as to the applicability of any specification or standard, the Facilities Technical Units owner of the Standard, shall seek guidance to the Standard Team.

1.6 PERSONNEL

Design, supervision of installation, commissioning, monitoring and maintenance of cathodic protection systems shall be carried out by competent specialized personnel as specified in the norm EN 15257 (Ref. /06/).

In particular the following requirements shall be verified:

– design shall be approved by a CP expert qualified at the 3rd level;

– during the execution of the field activities, an engineer qualified at the 2nd level shall always be present at site, in order to take prompt and real time decisions;

– elaboration and interpretation of the field data shall be approved by a CP expert qualified at the 3rd level.

Any deviation from above requirements shall be subject to the approval of the Company.

2 EXTERNAL CATHODIC PROTECTION

2.1 GENERAL

This section recommends procedures and considerations that apply for the design and implementation of cathodic protection systems of the external surfaces of storage steel tank bottoms with or without membrane in contact with tank foundation.

The objectives for the design of a cathodic protection system are:

- to protect the tank bottom from soil-side corrosion;
- to provide sufficient and uniformly distributed current;
- to provide a design life commensurate with the design life of the tank bottom or to provide for periodic anode replacement;
- to minimize interference currents;
- to locate and install system components where the possibility of damage is minimal;
- to provide adequate monitoring facilities to permit a determination of the system's performance.

2.1.1 Application.

Design of CP system is quite depend of the foundation system. Typical, tank foundation include a compacted granular fill above which a layer of sand is foreseen. In some case, an asphalt mat or an oil sand mat is applied above the sand, which will be directly in contact with the lower side of the tank bottom. In other case the tank foundation are in concrete.

The cathodic protection is required for external bottoms of new tanks that will be laid on a layer of sand, oiled sand or asphalt whereas is not required for external bottoms of new tanks that will be laid on concrete.

In presence of tank with secondary containment the anode system shall be installed between the membrane and the bottom of the tank. Any other solution will not allowed.

For existing tanks in presence of secondary containment the installation of CP system is not feasible.

2.1.2 Coatings

To reduce the levels of cathodic protection current the external surface should be coated.

The coating shall be properly specified to suit the installation and operating conditions, particularly temperature, and compatibility with cathodic protection.

Reference shall be made to ENI Company standard 20000.COR.CPI.STD Appendix C.

2.1.3 Electrical Earthing

Tanks to be cathodically protected should be preferable electrically isolated from plant earthing system to avoid current drainage.

In presence of tank with secondary containment, the membrane electrically insulates the tank bottom from the ground.

2.1.4 Sand Requirements

The sand used for tank foundation shall be clean, screened and debris free and shall have a chloride content less than 10 ppm and in no case by sand-bituminous layer.

2.1.5 Tank Design and Feasibility of Cathodic Protection

The feasibility of installing a cathodic protection system for protecting the external side of tank bottoms is summarized in the following tables.

Table 2.1 –Tank design and cathodic protection feasibility. New tank

Tank design	Feasibility of cathodic protection
Membrane under tank bottom with clean sand pad, with or without connection to earthing systems.	Feasible if minimum distance between membrane and tank bottom observed, excellent conditions for ensuring effectiveness of protection.
No membrane, with clean sand pad, no direct connection to earthing systems.	Feasible, excellent conditions for ensuring effectiveness of protection.
No membrane, with any kind of pad other than clean sand, no direct connection to earthing systems.	Feasible, but effectiveness depends on type and quality of pad.
No membrane, connection to an earthing systems.	Feasible, but effectiveness depends on type and quality of pad with higher current demand to apply.

Table 2.2 –Tank design and cathodic protection feasibility. Existing tank

Tank design	Feasibility of cathodic protection
Membrane under tank bottom with clean sand pad, with or without connection to earthing systems	Not feasible.
No membrane, with clean sand pad, no direct connection to earthing systems.	Feasible, excellent conditions for ensuring effectiveness of protection.
No membrane, with any kind of pad other than clean sand, no direct connection to earthing systems.	Feasible, but effectiveness depends on type and quality of pad.
No membrane, connection to an earthing systems.	Feasible, but effectiveness depends on type and quality of pad with higher current demand to apply.

2.2 BASE DATA FOR DESIGN

2.2.1 Tank Data

The following documentation and data are required for designing of the cathodic protection systems:

- maps of the area where the tank/s are located, indicating:

- the position of the structure to be protected;
- the position of other underground metallic structures;
- grounding networks of the electric system (type and extension);
- eventual structures in reinforced concrete;
- water table and site drainage

- construction drawings of the tank and foundations including dimensions, etc.;
- hazardous area classification;
- material specifications and manufacturer;
- external coating specifications;
- characteristics of the secondary containment if present:
  - type, materials;
  - the distance between the bottom and secondary containment;
- foundation material in contact with the tank bottom:
  - type;
  - characteristics: chemical composition, resistivity, granulometry, etc.
- life expectancy;
- electrical sectioning (position of insulating joints and/or flanges);
- temperature of the fluid contained in the tank;
- existence of paved ground surface
- existing or proposed cathodic protection systems in the area
- location of electric power sources

2.2.2 Design Reistivity

For anode system installed under the tank a design resistivity of dry sand (1000 ohm*m) shall be assumed when sizing the anodic system.

For anode system installed around the tank a design resistivity representative of the soil where the anode will be actually installed shall be assumed when sizing the anodic system. In this case a soil resistivity survey shall be performed to provide resistivity data for the design of anode systems. Location and depth for soil resistivity investigations shall be planned in accordance to the design of the anode systems. As a general guideline, resistivity data should be obtained at a minimum two location per tank.

2.3 DESIGN CITERIA

2.3.1 Design Life

The design life of the CP systems shall be at least equal to the design life of the tank. In the other case the design life of the CP systems shall be evaluated agreed with the company.

2.3.2 Protection Criteria

The cathodic protection system must guarantee the protection potentials reporting in the following table:

Table 2.3 – Guidance values of protection potential range vs Cu/CuSO4

Metallic material	Protection Potential V vs Cu/CuSO4	Limiting critical potential V vs Cu/CuSO4
Carbon steel structures aerobic environment	-0.85	-1.10 -1.00 (if for high strength steels >700 MPa)
Carbon steel structures anaerobic environment	-0.95	-1.10 -1.00 (if for high strength steels >700 MPa)

The protection potentials listed above are intended as true potentials, that is free from the ohmic voltage drop contribution in the soil. In order to eliminate the ohmic drop the most common technique consists in the instant-off potential measurement, recorded immediately after switching off the cathodic protection systems (of the impressed current type) active on the structure.

In case the minimum protection level cannot be achieved, the potential criteria reported in the norm EN 14505 (Ref. /5/) shall be applied.

2.3.3 Protection Current

Protection current is calculated considering surface area to be protected, protection current density (as defined in Table 2.4) and current drained to other metallic structures electrically connected to the surfaces intended to be protected (earthing system and reinforcing bars).

Recommended values for the protection current density to be used in the design of cathodic protection systems of tank bottom are reported in Table 2.4.

Table 2.4 – Indicative values of protection current density

Metal or structure	Current density, i_P mA/m^2
Bare steel	20
Copper wire [1]	150
Copper rod	50
Tinned copper wire	70
Zinc galvanised steel	20
Bare stainless steel	20
Steel rebar in concrete[2]	3

1: referred to the external diameter of copper wire
2: referred to concrete surface area

The current density shall be increased according to the tank normal operating temperature over 25°C by 1 mA/m2 per °C.

If the tanks bottom is coated, the "bare steel" values are to be used considering an incremental coating breakdown factor of 1.2% for each year.

Therefore for a design of 25 years : ip coated = ip bare x 0.3 (0.3 is 30% final coating breakdown factor)

In case of coated steel, the portion of the steel plate in correspondence to welds shall be considered as bare (also in case of fully coated plates, the paint will be destroyed by welding).

Protection current density shall be calculated as weighted sum of bare and coated portion. In absence of clear data, the following formula applies:

$$i_{P,\text{tank bottom}} = 0.5 \times i_{P,\text{bare}} + 0.5 \times i_{P,\text{coated}}$$

2.3.4 Safety Factor

In order to guarantee the smooth operation of the cathodic protection systems for the entire design life, the safety factor of 1.1 shall be considered to be applied to the calculated protection current density.

In addition the anode life exceeds the design life of the CP systems and the current output of transformer rectifier shall be 1.5 times minimum the design protection current.

2.4 DESIGN REQUIREMENTS FOR CATHODIC PROTECTION SYSTEM

2.4.1 Cathodic Protection System Type – New Tank

For cathodic protection of external surfaces of new tank bottoms impressed current systems are generally recommended, especially for large tanks and high resistivity soil.

Cathodic protection using galvanic anodes can be economically obtained if:

- the size of the tank is small;
- tank bottom is properly coated;
- the current requirement is low;
- the soil has a low resistivity (< 30 ohm*m);
- the tank is electrically insulated from neighboring metallic structures.

When a containment membrane is used, a linear distributed anode system shall be installed between the membrane and the bottom of the tank. In this case impressed current systems are recommended and the use of galvanic anode systems can be evaluated for small diameter tanks.

2.4.2 Cathodic Protection System Type – Existing Tank

Cathodic protection of external surfaces of existing tank bottoms shall be performed by impressed current systems. Cathodic protection by galvanic anodes shall not be accepted.

In presence of secondary containment the installation of CP system is not feasible.

2.4.3 Anode Material Selection

2.4.3.1 Galvanic Anode

Galvanic anode materials shall be magnesium or zinc.

Zinc anodes have a lower capacity and a smaller driving voltage against carbon steel than magnesium anodes.

The choice between magnesium and zinc also depends on design life requirements and economic considerations.

Design requirements are covered in the ENI Company standard 27964.ENG.COR.STD (Ref. /14/).

2.4.3.2 Impressed Current Anode

Anode materials shall be:

- mixed metal oxide (MMO) activated titanium – tubular or strips;
- mixed metal oxide (MMO) activated titanium – ribbon or grid;
- mixed metal oxide (MMO) activated titanium – wire;
- high chromium silicon iron – solid or tubular.

The selection of the anode material depends on the individual application.

Design requirements are covered in the ENI Company standard 20305.ENG.COR.STD (Ref. /15/).

2.4.4 Impressed Current Anode System Configuration

The favourite anode system configuration consists in linear distributed anodes placed in the soil directly under the tank, with or without membrane.

Alternatively the following anode configuration shall be evaluated:

- shallow distributed anode, with individual anodes distributed around the perimeter of the tank or under the tank bottom. Anodes shall be installed with backfill or pre-packed with backfill. Adequate venting shall be foreseen for anodes installed in paved areas;
- shallow groundbeds, with anodes grouped in few anodes groundbeds. The same requirement as per shallow distributed anodes apply;
- deep vertical groundbeds, according to ENI Company standard 05019.ENG.COR.STD (Ref. /16/).

2.4.4.1 Linear Distributed Anodes

Linear distributed anodes guarantee achievement of uniform protection and current distribution also in presence of geometrical constraints.

The anode type can be expanded mesh Ti-MMO grid or Ti-MMO ribbon laid between the lower side of the tank bottom and the secondary containment membrane.

The anodic structure usually consists of primary anodes - in the shape of ribbons, grid or grid strips - that supply the current, and secondary anodes (or distributors) that distribute the current from the cable connecting points to the primary anodes.

The configuration of the anodic structure, the number of connections between the anodes, distributors and cables must be such that the voltage drops, at the maximum current, are less than 300 mV inside the anode system.

Besides maintaining the resistance drops in the metallic conductors below the above-mentioned limit of 300 mV, the number of cable-distributor and distributor-anode connections must guarantee adequate redundancy. This guarantees the functioning of the cathodic protection system even if some connections break.

The connection points of the cables with the secondary anodes must be electrically insulated from the environment.

Distance between adjacent anode grid or ribbon shall not exceed 4 times the distance between anode and tank bottom. In this regard, in the design phase of the tank foundation, the membrane shall be installed approximately 0.5 m below the tank.

To determine the optimum spacing in relation to the environment resistivity and the distance between the cathode and anode system, it is suggested to use models for the calculation of electric field distribution such as Finite Elements.

Alternatively to the grid anode configuration, a number of Ti-MMO wire anode loops can be installed between tank bottom and the membrane.

2.4.5 Galvanic Anode System Configuration

The favourite anode system configuration consists in linear distributed anodes placed in the soil directly under the tank, with or without membrane. The anode type can be magnesium or zinc ribbon installed in a number of loop between tank bottom and membrane.

Alternatively shallow distributed anode configuration shall be evaluated, with Mg or Zn anodes distributed around the perimeter of the tank or under the tank bottom.

The anode to tank connections should be made inside a junction box, in order to allow current measurements and control, if requested.

2.4.6 Monitoring System

Cathodic protection monitoring is performed by potential measurements and shall be considered in the design phase.

For the cathodic protection monitoring permanent reference electrodes installed under tank bottoms shall be used. Applicable permanent reference electrodes shall be high purity zinc with backfill.

Number of reference electrodes to be installed under tank bottom depends on tank diameter. Minimum numbers are specified in Table 2.5.

Table 2.5 – Reference electrodes under tank bottoms

Tank diameter	Number of reference electrodes	Location
< 4 m	1	At the center
from 4 m to 20 m	4	equidistantly located one (1) m from the edge of the tank
>20 m	8	equidistantly located one (1) m from the edge of the tank

Watering pits fitted with solid PVC pipe shall be installed for electrodes periodical flooding operation, to prevent dry-out.

As integral part of the permanent monitoring system, plastic PVC pipes (access pipes) shall be permanently installed below the tank bottom and routed outside the tank.

The number of PVC access pipes shall be defined during the design phase.

Reference electrode access piping must have some means of contact with the electrolyte. This contact can be through the use of holes, slits, or not capping the end of the piping beneath the tank.

Perforations and slots should be designed to minimize entry of tank pad material.

Portable reference electrodes shall be inserted through the inside diameter of the access pipe. Inserting a reference electrode with metallic tape, bare wires, etc., may adversely affect potential readings.

Installation of external probe is also recommended with the aim to monitor both cathode potential and current density.

2.5 MATERIAL

2.5.1 Galvanic Anode

Galvanic anode materials shall be magnesium or zinc.

Material requirements are covered in the ENI Company standard 27964.ENG.COR.STD (Ref. /14/).

2.5.2 Impressed Current Anode

Anode materials shall be:

- mixed metal oxide (MMO) activated titanium – tubular or strips;
- mixed metal oxide (MMO) activated titanium – ribbon or grid;
- mixed metal oxide (MMO) activated titanium – wire;
- high chromium silicon iron – solid or tubular.

Material requirements are covered in the ENI Company standard 20305.ENG.COR.STD (Ref. /15/).

2.5.3 Permanent Reference Electrode

General features of permanent reference electrodes to be installed under tanks bottoms and underground drums, are summarized here below:

- type: high purity zinc + backfill;
- lead wire: 1 x 6 mm2
- backfill composition: gypsum 75%, bentonite 25%.

Zinc chemical composition shall be in accordance to the following table:

Table 2.6. Zinc reference electrode chemical composition

Element	Weight %
Al	0.1-0.5
Cd	0.025-0.07
Cu	0.005 max
Fe	0.005 max
Pb	0.006 max
Others	0.1 max
Zn	Rem to 100

2.5.4 Transformer Rectifier

Transformers/rectifiers shall comply with IEC 60076, IEC 60726 and IEC 60947.

Rectifiers shall be of a special design for cathodic protection service and shall be 3 phase units, or single phase.

Cathodic protection feeding units shall be transformer rectifiers with maximum allowed exit voltage of 50 V.

Both air cooled and oil cooled units are allowed, depending on local environmental conditions and unit design parameters.

Transformer rectifiers can be installed outdoor or indoor. Transformer rectifiers shall be installed outside hazardous areas. The DC ripple shall not exceed 5%.

To allow the ON/OFF potential measurements, the transformer rectifier shall be equipped with a breaker, inserted on the negative output circuit. The type and characteristic of breakers shall be adopted to the maximum nominal current output.

Alternatively, to allow the ON/OFF potential measurements, a removable and suitable sized copper link shall be incorporated in negative circuit to possibly connect a portable timer switch.

2.5.5 Cable

The cables shall be tin-coated, stranded single core copper with XLPE/PVC insulation or equivalent (for example HEPR/PVC).

The minimum rating for all cables and wires shall be 600/1000 Volt grade. The minimum cable sizes shall be as follows:

- positive and negative cathodic protection station cables: 25 mm2;
- monitoring cables: 10 mm2;
- impressed current anode cable tails: 10 mm2;
- magnesium/zinc anode cable tail and bonding cable: 10 mm2;
- reference electrode cable tails: 6 mm2. All above ground cables shall be suitably identified with tags.

2.5.6 Other Components

For other components of the cathodic protection systems, reference shall be made to the ENI Company standard 27589.ENG.COR.STD.

2.5.7 Safety

Cathodic protection systems shall be designed considering the hazardous area classification for the plant facility.

CP system equipment, including transformer rectifier units, junction and control boxes, test posts, shall be preferably installed outside classified area.

2.6 INSTALLATION

The installation specification shall be issued during the detail design phase.

The specification shall include as a minimum the following:

- procedure for installation of anode system;
- procedure for installation of permanents electrodes and coupons;
- procedure for installation of cables;
- procedure for cable connections;
- procedure for installation of transformer rectifiers;

- procedure for installation of junction boxes;
- procedure for installation of test post.

2.7 PRE-COMMISSIONING

During detailed design a pre-commissioning test specification shall be issued which covers all aspects of tests during mechanical completion and pre-commissioning testing.

Such tests shall include as a minimum:

- trial operation of anodes including individual anode loop resistance to earth immediately after completion of tank foundation and before tank plates are installed and then after the tank has been fabricated and power sources to confirm they can deliver their maximum capacity;
- measurements and testing shall also be carried out to confirm satisfactory connection of all cables and circuits;
- resistance to earth testing of all distributed groundbeds;
- calibration of permanently installed reference electrodes.

2.8 COMMISSIONING

The inspection and maintenance specification shall be issued during the detail design phase.

In this specification shall be defined the minimum requirements for the execution of ordinary periodical inspections of cathodically protected tank.

The specification shall include as a minimum the following:

- procedure and frequency for cathodic protection systems visual inspection;
- procedure and frequency for voltage and current measurements at feeding units;
- procedure and frequency for potential measurement.

2.9 INSPECTION AND MAINTENANCE

The inspection and maintenance specification shall be issued during the detail design phase.

In this specification shall be defined the minimum requirements for the execution of ordinary periodical inspections of cathodically protected tank.

The specification shall include as a minimum the following:

- procedure and frequency for cathodic protection systems visual inspection;
- procedure and frequency for voltage and current measurements at feeding units;
- procedure and frequency for potential measurement.

2.10 DOCUMENTATION

A detail design package shall be issued for cathodic protection systems of buried structures in plant facilities.

The design package shall include the following documents as a minimum:

- calculation notes;
- layout installation drawings showing: anode location; feeding cable routes; transformer rectifiers location; junction boxes location; test post locations; permanent reference electrodes;
- transformer rectifiers drawings;
- junction boxes drawings;
- typical installation drawings for groundbeds;
- material specifications and datasheets;

- installation procedure specification;
- inspection test plan for materials;
- inspection test documentations;
- commissioning specification;
- operating manual for transformer rectifiers;
- inspection and maintenance specification.

3 INTERNAL CATHODIC PROTECTION

3.1 GENERAL

The objective of using cathodic protection is to control the corrosion of the internal surface of carbon steel tank used for the storage of water, seawater, crude oil or hydrocarbons.

This section gives procedures and considerations that apply for the design and implementation of cathodic protection systems of the internal submerged surfaces of steel tank including bonded equipment.

The objectives for the design of a cathodic protection system are:

- to protect from corrosion the internal surfaces of steel tank in contact with water, including bonded equipment;
- to provide sufficient and uniformly distributed current;
- to provide a design life commensurate with the design life of the tank or to provide for periodic anode replacement;
- to locate and install system components where the possibility of damage is minimal;
- to provide adequate monitoring facilities to permit a determination of the system's performance.

Deviation, if any, shall be agreed with the Company.

3.1.1 Applications

Except for particular cases duly justified, the internal surfaces of tanks in contact with an electrolyte shall be cathodically protected by galvanic anodes.

Cathodic protection systems shall also be provided for all water storage tanks (fire fighting water, sea and brackish water, service water and potable water), except for demineralized water.

The selection of the proper cathodic protection system for water storage tanks, either impressed current or galvanic anodes, shall be addressed on a case by case basis during the detailed design.

3.1.2 Linings (internal Coatings)

To reduce the levels of cathodic protection current the internal submerged steel non or low alloyed) surface shall be coated.

The lining should be properly specified to suit the installation and operating conditions, particularly temperature, and compatibility with cathodic protection.

Linings shall be applied after all the anodes installation activities are completed and the cable connections are tested. Anodes shall be properly protected to prevent any coverage by the lining material.

Usually the lining system shall be allied to the tank bottom and to the wall for an height not less than the foreseen maximum water level.

Reference shall be made to ENI Company standard 20000.COR.CPI.STD. Appendix C.

3.2 BASE DATA FOR DESIGN

3.2.1 Tank data

The following documentation and data are required for designing of the cathodic protection systems:

- dimensions of the tank, including all submerged surfaces (e.g., wet risers on elevated tanks);
- area of submerged steel surfaces (e.g., support columns, ladders, baffles, braces, struts);
- submerged metallic components or accessories constructed of other than carbon steel (e.g., stainless steel, copper, and galvanized steel);
- chemical analysis of the water (dissolved gas, H2S, CO2, etc.);
- water conductivity;
- pH;
- water levels (minimum, maximum and average);
- seasonal variation in water composition;
- frequency and rate of emptying and filling the tank;
- type, specification, and condition of internal coating system;
- whether or not the water is subject to freezing;
- average and extreme water temperature;
- flow patterns, recirculation, aerators, heaters, riser pipes, velocity;
- other pertinent information.

3.2.2 Electrical Continuity

The structure to be protected needs to be electrically continuous. Individual components of the structure need to be connected with low resistance (<0.1 Ohm) metallic bonds.

3.2.3 Different Material

It is necessary to consider all the possible operating conditions and then determine whether or not a range of protection criteria can be established.

If different metals are protected by cathodic protection, then the least noble metal needs to reach its protection potential.

It is essential that the protection potential ranges of the various metals are not incompatible.

3.3 DESIGN CRITERIA

3.3.1 Design Life

The design life of the CP systems shall be at least equal to the design life of the tank. In the other case the design life of the CP systems shall be evaluated agreed with the company.

3.3.2 Protection criteria

The potential criteria shall be in accordance with the requirements of the norm EN 12499 (Ref. /2/).

Some practical protection potential are listed in the following table.

Table 3.1 – Guidance values of protection potential range vs Ag/AgCl

Metallic material	Protection Potential V vs Ag / AgCl	Limiting critical potential V vs Ag / AgCl
Low-alloy carbon steel T<40°C, aerobic environment	-0.80	-1.1
Low-alloy carbon steel T>40°C, aerobic environment	-0.90	-1.1
Low-alloy carbon steel anaerobic environment	-0.90	-1.1
Low-alloy carbon steel acid water pH<6	-0.90	-1.1
Stainless steel	-0.35	-
Copper and copper alloys	-0.45	-

When using silver/silver chloride reference electrode, temperature and chloride concentration in water must be known in order to correct the protection potential interval through the following equation:

$$E_{upper\ limit} = -0.816 - 0.059*\text{Log}\ [Cl\text{-}] - 0.6*(T-25)/1000$$
$$E_{upper\ limit} = -1.150 - 0.059*\text{Log}\ [Cl\text{-}] - 0.6*(T-25)/1000$$

Where $[Cl^-]$ is chloride content in mole/L, -0.6 mV/°C is Temperature Coefficient and T in the water temperature in °C.

3.3.3 Protection Current

Protection current is calculated considering surface area permanently or sequentially exposed to the electrolyte to be protected, protection current density , the coating breakdown factor and current drained to other metallic structures electrically connected to the surfaces intended to be protected (heating serpentines and support structures). It shall be calculated for the maximum, minimum and average levels of electrolyte.

Values for the protection current density to be used in the design of cathodic protection systems of internal tank surface are reported in the following

- 200 mA/m2 for bare carbon steel surface in contact with a reservoir water (high salinity and corrosivity) at ambient temperature;
- 80 mA/m2 for bare carbon steel surface immersed in seawater or an industrial water at ambient temperature;
- 20 mA/m2 for bare carbon steel surface immersed in potable water, fresh water or low corrosive water at ambient temperature;

For other metals like copper or stainless steel: as long as there is presence of carbon steel, current density requirement shall be the same as for carbon steel.

For other cases it shall be decided on a case by case basis, and will be subjected to Company approval.

If the tanks bottom is coated, the "bare steel" values are to be used considering an incremental coating breakdown factor of 1.2% for each year.

Therefore for a design of 10 years :

$i_{p\ coated} = i_{p\ bare} \times 0.12$ (0.12 is 12% final coating breakdown factor).

The current density shall be increased according to the tank maximum operating temperature over 25°C by 1 mA/m2 per °C.

For aluminium anode calculations, the following formula shall be used in order to take into account the reduction in electrochemical efficiency at elevated anode temperature:

$\varepsilon = 2433 - 27*(T - 20)$

ε is anode electrochemical efficiency in Ahr/kg

T is temperature in °C.

3.3.4 Safety Factor

In order to guarantee the smooth operation of the cathodic protection systems for the entire design life, the safety factor of 1.1 shall be considered to be applied to the calculated protection current density.

In addition the anode life exceeds the design life of the CP systems and the current output of transformer rectifier shall be 1.5 times minimum the design protection current.

3.4 DESIGN REQUIREMENTS FOR CATHODIC PROTECTION SYSTEM

3.4.1 Cathodic Protection System Type

Galvanic anodes cathodic protection systems shall be designed for crude oil or hydrocarbons storage tanks.

For water storage tanks cathodic protection using galvanic anodes can be obtained economically if:

- the size of the tank is small;
- the current requirement is low;
- the water has a low resistivity;
- the internal surfaces of the tank are coated.

Impressed current cathodic protection is generally recommended, for large tanks and where there are high resistivity of the water.

For potable water storage tank it is recommended to verify the impact of the cathodic protection system on the quality (water composition) of the potable water.

3.4.2 Galvanic Anode Material Selection

For the protection of internal tank surfaces with sacrificial anodes, the following anodic materials may be used:

- Zinc
- Aluminium-Indium alloy
- Magnesium-Manganese alloy.

The anodes shall be flush-mounted or stand-off types, with a trapezoidal or half-cylindrical section and affected by an utilisation factor of 0.8 (flush-mounted) or 0.85 (stand-off or suspended).

The type of anodic material shall be selected according to the following criteria:

- Zinc: for design temperatures lower than 40°C and for water resistivity values less than 500 ohm.cm;
- Aluminium: for water resistivity values less than 500 ohm.cm
- Magnesium: for water resistivity values greater than 500 ohm.cm.

The use of magnesium anodes is excluded for the protection of tanks containing inflammable substances.

Zinc anodes cannot be used for fresh water tanks. Aluminium alloy anodes can be used in absence of H2S.

Aluminium alloy anodes can be used only for water of high conductivity.

3.4.3 Anode System Configuration

Anode distribution inside each tank shall respect the following criteria:

- distribute the anodes as homogenously as possible (each anode shall protect approximately the same area);
- the anodes shall be placed so as to homogenously distribute protection current all over its respective surface area;
- anodes shall not be installed in positions which interfere with other structures (pipes, roof, etc.);
- the slope of the tank bottom may cause sediment accumulation in the peripheric area. In this area, anaerobic conditions may be created and therefore anode distribution shall be carried out so as to prevent the negative effects that this condition may cause.

For galvanic anode system the proper configuration shall be evaluated during detailed design, based on tank sizes and anodes throwing power using the following empirical formula

$$L_{\max} \cong \frac{1}{\sqrt{2}} \sqrt{\frac{\Delta V \, \phi_{tube}}{(\rho + 0.8)(i + 0.1)}}$$

Dove i simboli rappresentano:

- Φ = electrolyte height
- ρ = electrolyte resistivity
- i = protection current density.

Or by a dedicated FEM analysis and verifiyng that the anode throwing power is ≥ to half anode distance.

3.4.3.1 Impressed Current Anode System Configuration

Impressed current anodes (tubular anode strings, rod anodes or wire anodes) shall be vertically suspended inside the tanks by means of insulating supports, for instance a plastic rope tensioned between tank roof and bottom.

3.4.3.2 Galvanic Anode System Configuration

Galvanic anodes for crude oil or hydrocarbons storage tanks shall be installed on tank bottom.

Anodes can be either stand-off type or flush mounted type bolted to brackets permanently affixed to tank surface.

For flush-mounted anode, the anode face applied to protected area shall be suitably coated.

For water storage tanks, galvanic anodes can be either vertically suspended from tank roof or installed on tank bottom.

3.4.4 Monitoring System

The cathodic protection monitoring shall be considered in the design phase and shall be performed by potential measurements with the following equipment:

Permanent reference electrode

Permanent reference electrodes shall be generally provided to monitor the efficiency of the cathodic protection by measuring directly the structure to electrolyte potential at the spot where they are located

For tanks, one or several reference electrode(s) depending on diameter and electrolyte levels shall be mounted on fixed supports or suspended from the room close to the protected area.

Permanent electrodes position, type and number together with installation details shall be defined in the detailed design of the protection cathodic system.

Monitored anodes

For large tanks (diameter > 10 m), one (or several) anode(s) can be fitted to monitor their output current. The (these) anode(s) is (are) isolated with isolating joints from the structure and the anode(s) output current (s) is (are) monitored through a calibrated shunt.

Permanent reference electrodes (except if mounted on a flange) and monitored anodes cables are installed in such a way that the measurements are carried out from the exterior side by a system passing through the wall of the structure or the roof (for tanks), in order to monitor permanently the protection without penetration in the structure.

Cable insulation shall be suitable for the electrolyte and mechanically protected under rigid and fixed conduits for tanks.

Test stations may group several electrodes or monitored anodes and shall be located outside hazardous areas, preferably at ground level.

3.5 MATERIAL

3.5.1 Galvanic Anode

For the protection of internal tank surfaces with sacrificial anodes, the following anodic materials may be used:

- Zinc
- Aluminium-Indium alloy
- Magnesium-Manganese alloy.

Material requirements are covered in the ENI Company standard 27589.ENG.COR.STD (Ref. /13/).

3.5.2 Impressed Current Anode

Impressed current anodes shall be Mixed Metal Oxide Titanium type suitable for the electrolyte characteristics.

The following shape can be selected:

- tubular or rod anodes. Single anode or multiple anode preassembled on a feeding cable;
- wire anode;
- copper cored wire anode.

Material requirements are covered in the ENI Company standard 27589.ENG.COR.STD (Ref. /13/).

3.5.3 Permanent Reference Electrode

General features of permanent reference electrodes to be installed inside tanks, are summarized here below:

- type: Ag/AgCl;
- lead wire: 1 x 6 mm^2 min.

3.5.4 Transformer Rectifier

Transformers/rectifiers shall comply with IEC 60076, IEC 60726 and IEC 60947.

Rectifiers shall be of a special design for cathodic protection service and shall be 3 phase units, or single phase.

Cathodic protection feeding units shall be transformer rectifiers with maximum allowed exit voltage of 50 V.

Both air cooled and oil cooled units are allowed, depending on local environmental conditions and unit design parameters.

Transformer rectifiers can be installed outdoor or indoor. Transformer rectifiers shall be installed outside hazardous areas. The DC ripple shall not exceed 5%.

To allow the ON/OFF potential measurements, the transformer rectifier shall be equipped with a breaker, inserted on the negative output circuit. The type and characteristic of breakers shall be adopted to the maximum nominal current output.

Alternatively, to allow the ON/OFF potential measurements, a removable and suitable sized copper link, shall be incorporated in negative circuit to possibly connect a portable timer switch.

3.5.5 Cable

Underwater feeding cable shall be in accordance with the ENI Company standard 27589.ENG.COR.STD.

The minimum cable sizes shall be as follows:

- positive and negative cathodic protection station cables: 25 mm^2;
- monitoring cables: 10 mm^2;
- impressed current anode cable tails: 10 mm^2;
- reference electrode cable tails: 6 mm^2.

All cables shall be suitably identified with tags.

3.5.6 Other Components

For other components of the cathodic protection systems, reference shall be made to the ENI Company standard 27589.ENG.COR.STD.

3.5.7 Safety

Cathodic protection systems shall be designed considering the hazardous area classification for the plant facility.

CP system equipment, including transformer rectifier units, junction and control boxes, test posts, shall be preferably installed outside classified area.

3.6 INSTALLATION

The installation specification shall be issued during the detail design phase.

The specification shall include as a minimum the following:

- procedure for installation of anode system;
- procedure for installation of permanents electrodes;
- procedure for installation of cables;
- procedure for cable connections;
- procedure for installation of transformer rectifiers;
- procedure for installation of junction boxes;
- procedure for installation of test post.

3.7 PRE-COMMISSIONING

During detailed design a pre-commissioning test specification shall be issued which covers all aspects of tests during mechanical completion and pre-commissioning testing.

Such tests shall include as a minimum:

- measurements and testing shall also be carried out to confirm satisfactory connection of all cables and circuits;
- calibration of permanently installed reference electrodes.

3.8 COMMISSIONING

Commissioning procedures shall be issued during detailed design for the approval of the COMPANY.

The purpose of the commissioning procedure shall be used to show that the installed systems operate as specified and that the required design criteria have been met. The specification shall include as a minimum the following:

- standard forms for recording commissioning results;
- procedure for setting the cathodic protection systems in operation and measuring ON potentials;
- procedure for measurement of IR free potentials.

The supplier of the cathodic protection system shall successfully carry out the commissioning of the system to be witnessed by COMPANY.

3.9 INSPECION AND MAINTENANCE

The inspection and maintenance specification shall be issued during the detail design phase.

In this specification shall be defined the minimum requirements for the execution of ordinary periodical inspections of cathodically protected tank.

The specification shall include as a minimum the following:

- procedure and frequency for cathodic protection systems visual inspection;
- procedure and frequency for voltage and current measurements at feeding units;
- procedure and frequency for potential measurement.

3.10 DOCUMENTATION

A detail design package shall be issued for cathodic protection systems of buried structures in plant facilities.

The design package shall include the following documents as a minimum:

- calculation notes;
- layout installation drawings showing: anode location; feeding cable routes; transformer rectifiers location; junction boxes location; test post locations; permanent reference electrodes;
- transformer rectifiers drawings;
- junction boxes drawings;
- typical installation drawings for anode system;
- material specifications and datasheets;
- installation procedure specification;
- inspection test plan for materials;
- inspection test documentations;
- commissioning specification;
- operating manual for transformer rectifiers;
- inspection and maintenance specification.