



Exploration & Production

GENERAL SPECIFICATION

CORROSION

GS COR 110

External cathodic protection of buried pipelines

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1. Scope

This document defines the minimum requirements for the design, installation and commissioning of external cathodic protection of buried pipelines used for hydrocarbons, gas or water transportation according to site conditions and their immediate environment.

It applies to low carbon steel or stainless steels, coated or uncoated pipelines, including buried equipment installed along their routes such as sectioning valves, tees, anchoring flanges.

It also applies to buried production flowlines between wellheads and intermediate stations and/or treatment centres.

It does not apply to the onshore facilities located in restricted areas such as wells, intermediate stations, treatment or storage centres. Cathodic protection of these facilities is specified in [GS COR 111](#).

2. Reference documents

The reference documents listed below form an integral part of this General Specification and apply when they are not in conflict with those of the present document. Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the EFFECTIVE DATE of the CONTRACT. Should some requirements of these documents differ, those from [ISO 15589-1](#) prevail.

Standards

Reference	Title
ISO 15589-1	Petroleum and natural gas industries – Cathodic protection for pipeline transportation systems
ISO 13623	Petroleum and natural gas industries – Pipeline transportation system
EN 12954	Cathodic protection of buried or immersed metallic structures - General principles
EN 13509	Cathodic protection measurement techniques
ISO 8044	Corrosion of metals and alloys - Basic terms and definition
BS 1591	Specification for corrosion resisting high silicon iron castings.
BS 7361 Part 1	Cathodic protection Part 1: code of Practice for land and marine applications
BS 1377 Part 3-9	Methods of tests for soils for civil engineering purposes Part 3: Chemical and electrochemical tests Part 9: In situ tests
IEC 79	Electrical apparatus for explosive gas atmospheres
IEC 227	Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V
IEC 146	Semiconductor convectors
IEC 364	Electrical installation of building: scope

Reference	Title
IEC 529	Degrees of protection provided by enclosures (IP code)
IEC 502	Characteristics and constitution of cables

Professional Documents

Reference	Title
NACE RP 0169	Control of external corrosion on underground or submerged metallic piping systems
NACE RP 0286	The electrical isolation of cathodically protected pipelines
NACE RP 0572	Design, installation, operation and maintenance of impressed current deep ground beds
NACE RP 0177	Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems

Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
GM COR 020	Principles of utilisation and rules of calculation for insulating joints

Total General Specifications

Reference	Title
GS COR 111	External cathodic protection of onshore facilities
GS COR 201	Supply of sacrificial anodes
GS COR 210	Insulating joints
GS COR 220	Three layer polyethylene external coating for pipelines
GS COR 221	Three layer polypropylene external coating for pipelines
GS COR 350	External protection of structures and equipment by painting
GS COR 420	External field coatings of pipelines
GS ELE 079	Electrical apparatus for explosive gas atmosphere

3. General requirements

3.1 Qualification and Certification of Cathodic Protection specialists responsible for the design

In any case, design of cathodic protection systems to be installed on buried pipelines shall be carried out exclusively by competent specialised personnel. The qualification of each of the specialists working for such a design shall be demonstrated by the CONTRACTOR to the COMPANY before commencement of the job. Therefore the verification of the formal Certification of the individuals shall be carried out as follows:

- Conventional design work to be carried out by level 2 certified personnel
- Complex design work or verification to be carried out by level 3 certified personnel.

Accepted Certification schemes are AFNOR Competence (Land Application Sector), APCE (Land Application Sector), Institute of Corrosion, NACE International. Any other Certification scheme should be approved by the COMPANY.

Any use of non certified personnel for cathodic protection design shall be subject to the approval of the COMPANY on a case by case basis (demonstration of competence through detailed curriculum vitae and description of experience).

3.2 Sub-contractors

The CONTRACTOR generally sub-contracts the study, works supervision, adjustments and commissioning, and the preparation of the final report to a specialised SUB-CONTRACTOR. The choice of SUB-CONTRACTOR shall be submitted to the COMPANY for approval.

Notwithstanding the above provision, the CONTRACTOR remains responsible to the COMPANY for the successful completion of the cathodic protection project and in no case may he override:

- The COMPANY's approval of the choice of SUB-CONTRACTOR
- The COMPANY's approval of the study report.

to release him from his contractual liability.

In the case of complex installations calling for the simultaneous intervention of several CONTRACTORS, a special contract should be awarded for the whole of the cathodic protection. If for any reason this is impossible, special dispositions in the contract will apply, to ensure coordination and compatibility of the various cathodic protection studies, the standardization of equipment, and the preparation of a common final report.

3.3 Definition of tasks

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

3.3.1 Study

The study comprises:

- The site survey, the collection of all relevant information, the measurements required for the estimation of corrosion risk and the evaluation of coating materials
- The collection of all documents and information concerning the design of the structure to be protected, its size, and those of its characteristics which are likely to influence the design of the cathodic protection system
- The collection of all documents and information concerning the environment of the work: the presence of nearby metallic structures whether cathodically protected or not, the presence of works likely to emit stray currents, the presence of high voltage cables or transmission lines, electric power stations, transformer stations, etc., which, if faulty, may damage cathodic protection installations, coatings, or the structures itself
- The collection of all information concerning the availability of electrical power for the supply of cathodic protection installations.

The preparation of a detailed study report comprising:

- An analysis of all information gathered and measurements taken, and an estimate of corrosion risks
- Justified design hypotheses, particularly for the insulation values of the coatings, and for ageing
- A technico-economical discussion of the various possible solutions
- Design notes justifying the sizing and layout of equipment: anodes, transformers-rectifiers, cables, etc. Unless otherwise specified, the cathodic protection system will be designed for a service life of 25 years minimum
- A list of materials, including assembly accessories, and the corresponding technical specifications
- A list of possible suppliers.
- Schematic diagrams
- Detailed equipment diagrams
- Detailed installation drawings, indicating:
 - The location of insulating joints
 - Electrical bonding to be installed

- Special insulations to be installed
- The layout of different types of equipment and the relevant installation procedure
- Wiring diagram for electrical equipment.
- Instructions proper to installations, indicating all precautions to be taken. Particular emphasis shall be placed on the construction of:
 - Ground beds
 - Connections on anode circuits
 - Insulations between protected and non protected parts
 - Insulations between parts protected by different systems
 - Insulations between parts protected by the same system, which must be separated temporarily for various operational reasons, such as routine checking of the quality of the coating, etc.
 - Influence correctors between the work to be protected and neighbouring works
 - Reference electrode installations at fixed points.

As a general rule, the location of electrical equipment in hazardous areas shall be avoided. If this is impossible, the use of equipment corresponding with the safety classification of the area in question will be specified.

The study shall be submitted to the COMPANY or to its representative for approval.

3.3.2 Administrative formalities

If local legislation requires that an enquiry takes place before a cathodic protection system is installed, the preparation of the legal file is the responsibility of the CONTRACTOR, and the study shall not receive definitive approval until the results of the official enquiry have been examined.

It shall be the COMPANY's responsibility to transmit the file to the competent administrative body. The COMPANY shall also receive the results of the enquiry.

The COMPANY shall be responsible for any questions of property which might be involved in the installation of the cathodic protection system. The COMPANY shall likewise deal with the acquisition of land and rights of way and settle all additional costs and compensation for any loss of crops.

The CONTRACTOR shall provide the COMPANY with all the information and documents required to deal with these property matters, including:

- Extracts of land survey maps
- Delimitation on the land survey maps of the land to be acquired and the temporary and/or permanent rights of way to be acquired.

If the installations require a power supply from the local distribution network, and unless otherwise specified the formalities with the local distribution COMPANY shall be carried out by the CONTRACTOR. However, the network extension and connection costs shall be borne by the COMPANY.

3.3.3 Equipment supply

Unless otherwise specified, supply of all the equipment shall be the responsibility of the CONTRACTOR. The CONTRACTOR shall also supply the spare parts recommended by the VENDOR for a two year operating period of this equipment.

The CONTRACTOR shall also supply all those spare parts which might be required during the starting-up period of the installation.

The CONTRACTOR shall make all the necessary arrangements with the VENDOR to allow the the COMPANY access at all times to the workshops during the manufacturing period to check:

- Manufacturing progress
- That the equipment conforms to the specifications
- And to be present during factory testings.

A provisional manufacturing schedule shall be handed to the COMPANY for planning of inspections.

The VENDOR shall supply the factory test reports, the anode material chemical analysis, the certificates of approval for electrical equipment to be used in hazardous areas, etc., to the CONTRACTOR who shall include them in the final report.

The final report shall consist of:

- A detailed description of the installation
- The VENDOR's drawings and the operating and maintenance instructions
- The as built drawings
- The equipment list with references and VENDOR's addresses
- The list of spare parts for two years of operation, with complete references
- The operating procedures
- The complete list of measurements taken before and during the starting up phase
- The reports stating the agreements taken with the COMPANYS of the neighbouring structures (duly signed by the various parties concerned) on the corrective measures to be taken for any interference of these structures

The results of the enquiry and the permission of the local authorities if the installations are to be in countries where such installations are subject to special legislation

4. Protection criteria

4.1 General

Unless otherwise indicated, all the requirements of [ISO 15589-1](#) shall apply.

In addition, and unless otherwise indicated in this document, all the requirements of [EN 12954](#), [NACE RP 0169](#) and [BS 7361 - Part 1](#) shall apply.

Unless justified by particular circumstances, any buried pipeline that requires cathodic protection must be electrically insulated from the other structures to which it may be connected.

4.2 Protection potential

The pipe-to-soil potential is used as a criterion for effective cathodic protection.

This potential is measured relative to a saturated copper/copper sulphate reference electrode.

The cathodic protection system shall permanently modify the electrochemical free potential of the entire protected surface of the pipeline in the negative direction, and over the upper limit as defined below.

- -850 mV/Cu/CuSO₄ for steel in an aerated soil
- -950 mV/Cu/CuSO₄ for steel in a de-aerated soil with confirmation of the presence of active sulphate reducing bacteria.

To avoid detrimental effects on the applied coating by cathodic disbonding or hydrogen induced stress cracking on steel, the potential shall not exceed a too negative potential. This overprotection potential may vary from -1.2 V/Cu-CuSO₄ for a low carbon steel pipe in an aerated soil to -1.0 V/Cu-CuSO₄ for a high strength steel pipe.

These values of potential have to be measured as close as possible from the "true" values, correcting the error due to the ohmic drop in the soil.

More specific protection criteria may be accepted by the COMPANY on a case per case basis, according to pipeline characteristics, coating and surrounding site.

5. Site studies

5.1 Site surveys

Before the definition of the cathodic protection design, the CONTRACTOR shall undertake a site survey including:

- Soil resistivity measurements along the pipeline route to assess the apparent aggressiveness level and, at points either side of the route, for the installation of impressed current anodes
- Measurements of pipe-to-soil potentials, if applicable, on existing, crossed and parallel buried metallic structures (pipelines, rails) or on the existing pipeline to be protected at accessible points
- A list of low voltage power lines which may be used to feed an impressed current DC source, and high voltage lines, which may have a detrimental influence
- A list of existing cathodic protection equipment on crossed and parallel buried structures in the vicinity of the pipeline route.

Note: In the case of an existing pipeline, the CONTRACTOR may, conditions permitting, carry out one or more of the cathodic protection trials, so that the apparent insulation resistance and initial current requirement can be evaluated.

5.2 Soil resistivity measurements

Soil resistivity shall be measured by the four aligned and equidistant pins method (Wenner's method), using an instrument especially designed according to the following minimum requirements:

5.2.1 Along the pipeline route

5.2.1.1 Distance (a) between two successive pins

$$a = 1.3 \times c \text{ and } 1.3 \times (c + \Phi) \text{ (m)}$$

With:

- C: average soil thickness above the upper pipe generatrix (m), and
- Φ : outer diameter of the pipe (m)

5.2.1.2 Frequency of measurements

Measurements shall be carried out:

- every 1 or 2 kilometres (according to the accessibility of the route), with intermediate measurements when the ratio of resistivity values for the same distance between electrodes becomes greater than 2.
- at crossings with existing pipelines, DC electrified railway and high voltage power line
- when there is a visible change in the nature of the soil at ground level.

5.2.2 At pre-selected points for impressed current anode ground beds

These points shall be located in the vicinity of an available low voltage power line or in areas of low resistivity, at appropriate intervals outside the pipeline route and accessible to an excavator.

Anode configuration (Section 8.5.3.2)	Distance from pipeline route and any other buried metallic structures (m)	Distance between consecutive points (m)
Configuration 1	60, 100 and 150	1.5 and 3
Configuration 2	20 and 30	5, 10, 15 and 25

Notes:

- The location of the pre-selected points can be either side of the pipeline route, as chosen by the CONTRACTOR with approval of the COMPANY, but outside of any hazardous areas
- If soil resistivity survey results are supplied to the CONTRACTOR, the CONTRACTOR may proceed to check them at random every 3 to 5 km along the pipeline route and at selected points for impressed current anodes.

5.2.3 Results

The results shall be set out in the form of a table, specifying the place, kilometric position, distance between points, corresponding resistivity value and any observations concerning ground level.

A profile of soil resistivity ($\log \rho = f(l)$) along the pipeline route shall be prepared.

5.3 Existing metallic structures

Unless the data is supplied to the CONTRACTOR by the COMPANY, existing metallic structures, buried or in contact with the soil, crossed and parallel, shall be identified and their

owners contacted to obtain the necessary information concerning their structures, to obtain authorisation to carry out potential measurements and to ascertain their particular technical requirements with respect to the new cathodic protection system:

- Pipeline
 - Year of construction
 - Overall diameter and grade of steel
 - Coating systems (pipe and weld joints)
 - Cathodic protection system (impressed current or sacrificial anodes, and test points located in the vicinity of the pipeline route, present protection level)
 - Technical requirements (common test facilities, cable connection method, specific insulation).
- Railway
 - Electrical power supply (AC or DC)
 - The nearest DC substation
 - Presence of insulating joints on rails close to the pipeline route.

At each test point on the existing pipeline and rail crossing point, the potential with respect to a portable Cu-CuSO₄ reference electrode shall be measured. When the potential varies by more than 50 mV, a recording over 30 to 60 minutes shall be taken.

5.4 High voltage power lines

Unless otherwise indicated, only power lines with a voltage greater than or equal to 60 kV shall be taken into account.

These include:

- Those that cross the pipeline route
- Those that remain parallel to the pipeline route, within a strip 500 m either side of the pipeline route.

For each, the survey shall include:

- The identification reference fixed to the pylons
- Nominal voltage between phases
- Pylon type and base dimensions at ground level
- Shortest distance from pylons to pipeline
- Presence of electrical interconnection between pylons (guard cable).

5.5 Direct or alternating stray currents and telluric currents

Site surveys shall verify whether the pipeline is subjected to DC or AC stray currents or telluric currents. In this case, the protection system's design should enable maintenance of the polarisation potential within the above stated limits 95% of the time and, in the case of alternating current, protecting the personnel against any electrical hazard.

6. Electrical insulation of the pipeline

The pipeline may:

- Include steel casings, intermediate stations comprising other metallic structures in contact with the ground, river crossings, arrivals (or departures) of steel sea lines on beaches
- Be connected to future or existing pipelines, to large metallic structures in contact with the ground such as wells, treatment or storage centres.

The pipeline's cathodic protection system shall be segregated from the other metallic structures by the provision of electrical discontinuity.

The CONTRACTOR shall indicate, in the detailed study, the means and equipment proposed to ensure such electrical isolation (insulating joints, insulating plates, centering tools, closing plates). However, these shall be designed in accordance with safety rules with respect to overvoltage protection, and satisfy the requirements below.

6.1 Insulating joints

Except if otherwise approved by the COMPANY, the pipeline ends, including at intermediate stations and branching points, shall be fitted with an insulating joint of the monolithic or flanged type depending on the fluid transported.

In the case of monobloc insulating joints with a diameter greater than or equal to 50 mm, the requirements of the document **GS COR 210** shall apply. In other cases, the type of insulating joint shall be submitted to the COMPANY for approval and shall satisfy the requirements of **NACE RP 0286**.

In all cases, the insulating joints shall comply with the construction and operating conditions of the pipeline: steel grade, fluid transported, pressure, temperature, etc.

When positioning them, particular attention shall be paid to the avoidance of any short circuit that might be caused by a support, walkway fittings (valve) or any other metal structure, whether temporarily or permanently installed. In addition, they shall be located above ground, on a straight section of the pipeline, and if the design permits, in an inclined plan, when the pipeline leaves or enters the ground, in order to avoid any risk of internal short circuit of insulating parts by internal deposits.

In the case of different cathodic protection systems for the pipeline -such as sacrificial anode protection in seawater sections or for long river crossings, and impressed current protection on land- an insulating joint shall be installed at the interface, in aerial exposition or underground in a watertight and accessible cellar.

If the fluid transported contains an aqueous phase, the insulating joint shall be coated on the inside and over sufficient length, on the side subject to cathodic protection, to minimize the risk of corrosion by short circuiting of the cathodic protection current. This length depends on the aqueous electrolyte resistivity and content and on the pipeline diameter. In absence of better calculation approach (as per **GM COR 020**, Total internal technical document, supplied on request when necessary), the length L to be coated may be defined according to following simplified formula:

$$L = 400 \frac{D}{\rho}$$

With:

- L: Internal coated length in centimetre
- D: Nominal diameter of pipeline in centimetre
- ρ : Electrolyte resistivity in Ohm.cm

6.2 Safety devices

On sites that are subject to frequent lightning effects (keraunic number normally over 21), the CONTRACTOR shall install safety devices such as surge diverters or polarization cells, which shall remain operational without requiring constant checking.

The CONTRACTOR shall then submit the selected device (or devices) to the COMPANY for approval, in accordance with recommendation [NACE RP 0177](#).

6.3 Earthing circuits

In order to limit the current losses, the cathodic protection pipeline shall be electrically isolated from earth circuits of pumping intermediate stations and treatment and/or storage centres.

Earthing devices may be required for security reasons. These devices shall be either equipment according Section 6.2 or separated earth points, composed of zinc alloy or galvanized steel, buried in backfill and situated near high voltage power lines (Section 5.4).

7. Pipeline coatings

In order to limit the number and capacity of cathodic protection systems used for external protection of buried surface pipelines, an external coating is applied.

The coating is applied in factory on line pipes and the field joint coating is applied with materials suitable for coating plant.

These plant coatings are generally:

- Three layer polyethylene (as per [GS COR 220](#)) or polypropylene (as per [GS COR 221](#)) based external coatings, with eventual concrete mechanical protection in the case of long river crossings
- Epoxy powder fusion bonded coatings.

Field joint coatings shall be executed in accordance with [GS COR 420](#) by:

- Restoring the plant coating with a similar coating
- Applying cold tape or heat shrinkable sleeve
- Applying a liquid coating.

Buried fittings such as sectioning valves shall be coated with a thick coating according to system P08 in [GS COR 350](#).

8. Calculation parameters and methods

The design bases specified below may be used to ensure that a cathodic protection system will work in normal operating conditions. They may be adapted in the job specification for specific sites or conditions, or by the CONTRACTOR subject to technical justification submitted to the COMPANY for approval.

The dimensioning parameters shall include:

- Current densities (J_p) to be applied to bare surfaces according to the type of material to be protected (steel, copper, rebar concrete, etc.)
- Current densities (J_{pr}) to be applied to the coated surface according to the coating system
- The percentage (x) of damaged coating area
- Surfaces to be protected (S)
- Actual weight consumption rate (m) or capacity (C) of the anodes used (sacrificial or impressed current types)
- The utilization factor (u) of the anodes
- The life
- Span (D) during which the cathodic protection system shall guarantee the minimum protection level as defined in Section 4.

8.1 Current densities

The different surfaces, bare (damaged coating, anchoring or earthing of line installations) and coated, shall be considered separately in current demand calculations.

Unless otherwise stipulated in the job specification, the densities (J_p) applicable to the bare metal below shall be adopted.

- Steel in soil: 10 mA/m² dry and 20 mA/m² wet
- Copper in soil: 50 mA/m² dry and 80 mA/m² wet
- Concrete reinforcements: 1 mA/m² (surface of concrete in contact with the ground)
- Steel covered of cement: 10 mA/m².

For coated steel surfaces, the table below gives the values to be adopted for the different coating systems and for old structures according to their age or for new structures according to the required life span.

**Percentage (x) of surface damaged
Current densities (J_{pr}) for coated surface (wet soil)**

Coating system (with thickness)	Age (years)	Percentage (x) of damaged surface	Current density J_{pr} (mA/m ²)
Coal-tar and bitumen enamel, 2 to 4 mm	< 10	2	0.4
	≥ 10	5	1
Fusion bonded epoxy, 0.4 mm	indifferent	0.5	0.1
Three-layer PE or PP, 1.5 to 2.5 mm	indifferent	0.25	0.05
Cold applied adhesive tapes, 1 to 2 mm	< 10	2	0.4
	≥ 10	5	1
Cold applied liquid epoxy, 0.4 mm	≥ 10	20	4

8.2 Protection current

To evaluate current demand, the CONTRACTOR shall take into account all the metal surfaces to be protected in the section of pipeline concerned, and apply the relevant current densities as defined in Section 8.1 for the specified life span.

The pipeline sectioning shall be defined from pre-selected points for DC current sources and soil resistivity profiles.

For each surface, the current demand is then equal to:

$$I = x.S. J_{pr}$$

With:

- I: Protection current for the surface considered (mA)
- S: Area to be protected (m²)
- J_{pr} : Current density values defined in Section 8.1 (mA/m²) for bare metals
- x: Percentage of area damaged for coated surfaces (%)

8.3 Number of DC sources

The number of DC sources distributed along the pipeline route is directly dependent on the average apparent electric characteristics of the pipeline at the end of the life span and the limiting potential criteria as defined in Section 4.

As a general rule, the distance between two consecutive DC current sources shall be limited to 40 km for an impressed current system and 5 km for a sacrificial anode system using magnesium anodes. This distance may increase in accordance with coating qualities.

However, a check shall be carried out based on theoretical equations adapted for a pipeline of finite length, as indicated in the appendix, each section being considered to be laid in a uniform electrolyte and with uniformly distributed constant characteristics. For more complex cases, modelling of the system shall be carried out demonstrating that a right level of potential will be reached at each location during the whole design lifetime using software approved by the COMPANY (e.g. PROCOR).

8.4 Anodic system

8.4.1 Anode weight

Depending on the type of anodes used, the minimum anodic weight (M expressed in kg) of the anodes to be installed, to ensure permanent operation of the DC sources for the specified life span (D), shall be equal to:

$$M = [(m \times I \times D) / u]$$

With:

- m: Weight consumption rate of anodic material (kg/A.year)
- I: Total current demand (A)
- D: Life span (years)
- u: Anode utilization factor

The weight consumption rate (m) of anodic material is:

- 0.45 kg/A.year for Iron/Silicon/Chromium anodes
- 9 kg/A.year for scrap steel
- 0.010 kg/A.year for magnetite anodes
- Negligible for MMO (mixed metal oxide anodes on titanium substrate) anodes
- 7.3 kg/A.year for magnesium sacrificial anodes.

The utilization factor (u) of the anodes is equal to:

- For scrap steel, Iron/Silicon/Chromium and Magnetite anodes: 0.85
- For sacrificial anodes: 0.80.

8.4.2 Number of anodes

Depending on the anodic weight, the current output required at each injection point is produced by one or more anodes, the number of which (N) is defined according to their unit current capacity (C) or unit current output (i) derived from the maximum current density:

$$N \geq [(I \times D) / C]$$

With:

- I: Total current required (A)
- D: Life span (years)
- C: Unit capacity of the anode (A.year)

or

$$N \geq I / i$$

With:

- I: Total current required (A)
- i: Maximum unit current of the anode (A)

The number calculated in this way results in an anodic weight greater than or equal to that calculated in Section 8.4.1.

8.5 DC current source dimensioning

After commissioning, each DC current source shall guarantee the upper protection limit (E_p) defined in Section 4, in the relevant pipeline sections. Dimensioning shall depend on the overall resistance (R) of the resulting electric circuit, calculated as indicated in Section 8.5.3.

8.5.1 Impressed current system

The output voltage (U in V) from the DC source (normally a transformer/rectifier set) shall provide a DC current output that is at least equal to the minimum total value (I) according to the maximum overall resistance of the anode/structure circuit:

$$U \geq 1.2 \times R \times I$$

With:

- I: Total current required (A)
- R: Maximum overall resistance (Ω)
- 1.2: Safety factor

Unless otherwise exempted, the DC voltage (U) shall not exceed 50 V.

The nominal current (I_n) of the DC source shall be at least equal to:

$$I_n \geq 1.25 \times I \text{ (A)}$$

8.5.2 Sacrificial anode system

The number of sacrificial anodes (N) and their dimensions, at each injection point, shall be defined to provide the total current required (I) and maintain a protection level (E in mV), throughout the anticipated life span, that is equal to or more negative than the protection limit (E_p) on the relevant pipeline sections:

$$E = E_a + (R_a \times I_a) \leq E_p$$

With:

- E_a : Anode potential in a closed circuit (mV)
- R_a : Maximum anode resistance (Ω)
- I_a : Anode unit current = $1.1 \times I/N$ (mA)

8.5.3 Calculating circuit resistance

8.5.3.1 Overall system resistance

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

$$R = R_{an} + R_{ca} + R_o \text{ (}\Omega\text{)}$$

With:

- R_{an} : Resistance of the anodic weight relative to the ground (Ω)
- R_{ca} : Resistance of the anode and cathode connecting cables (Ω)
- R_o : Apparent resistance of the pipeline sections from the DC current source (Ω)

Note: The apparent resistance of the pipeline sections (R_o) is not normally taken into account because of the safety factors already taken into account.

8.5.3.2 Anode resistance

Unless otherwise stipulated, two "anode ground bed" configurations may be considered, depending on:

- The dimensioning of the installation
- The apparent resistivity of the ground at the selected point
- The environment.

Configuration 1: shallow anodic ground bed with horizontal anodes laid in a continuous backfill bed.

The anode resistance (R_a) relative to the backfill, and the backfill bed resistance (R_b) relative to the natural ground is calculated using Dwight's formula, below:

$$R_a \text{ or } R_b = (\rho / 2\pi L) \cdot [\ln \{ (4L^2 + 4L \times \sqrt{(h^2 + L^2)}) / (d \cdot h) \} + (h/L) - (\sqrt{(h^2 + L^2)} / L) - 1]$$

With:

- ρ : Resistivity of the backfill (R_a) or the ground (R_b) ($\Omega \cdot m$)
- L : Length of the anode (R_a) or of backfill (R_b) (m)
- d : Diameter of the anode (R_a) or equivalent to the backfill section (R_b) (m)
- h : Twice the depth of the centre line of the anodes and of the backfill (m)

The overall resistance is then:

$$R_{an} = [(R_a \times f) / N] + R_b$$

With:

- f : Anode interaction coefficient
- N : Is number of anodes

Configuration 2: deep well anodic ground bed with vertical individual or string anodes in a backfill column.

The unit resistance of the anodes (R_a) relative to the backfill, and of the backfill column (R_b) relative to the natural soil is calculated using Dwight's formula below:

$$R_a \text{ or } R_b = (\rho / 2\pi L) \cdot [\ln (8L/d) - 1]$$

With:

- ρ : Resistivity of the backfill (R_a) or soil (R_b) ($\Omega \cdot m$)
- L : Length of the anode (R_a) or the backfill column height (R_b) (m)
- d : Diameter of the anode (R_a) or of the backfill column (R_b) (m)

The overall resistance is then:

$$R_{an} = [(R_a \times f) / N] + R_b$$

With:

- f : Anode interaction coefficient
- N : Number of anodes

8.5.3.3 Anode interaction factor

The interaction factor which is included in the above overall resistance calculations (R_{an}) is calculated using the following equation:

$$f = 1 + [(2.L/e).Ln (0.656. N)] / [Ln (8.L/d) - 1]$$

With:

- L: Length of the anode (m)
- d: Diameter of the anode (m)
- e: Average distance between two anodes (m)
- N: Number of anodes

8.5.3.4 Cable resistance

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

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

With:

- ρ_o : Resistivity of the cable core at 20°C ($\Omega.m$), equal to 0.18 μ ohms.m for copper
- l_c : Length of cables considered (m)
- s_c : Cross-sectional area of the cable core (m^2)

9. Equipment

9.1 Sources for the impressed current systems

9.1.1 Types

Selection of materials and installation for impressed current stations shall be in accordance with recognised international standards put as reference documents in the present specification.

This equipment is required to operate as a permanent generator connected to the circuit comprising the anode ground bed and the pipeline to be protected, and supplying:

- A constant current (controlled by transducer)
- A constant voltage (DC output voltage control)
- Constant potential (control of measured potential relative to a permanent reference electrode).

When a low voltage power supply (220/240 V single phase or 380/440 V three-phase) is available at a reasonable distance (≤ 500 m), a transformer-rectifier set shall be used. This will normally be of the air cooled type (natural or forced convection), unless otherwise stipulated, in particular for an outdoor installation in desert climate conditions, for which an oil cooled type is preferred.

If there is no low voltage power supply, the DC source shall be self-powered and comprise electronic regulation, associated with:

- Either a set of gas thermo-generators, particularly on pipeline carrying a gas that can be used for their feed
- Or a set of solar panels and batteries.

In the case of self-powered DC sources, the power drawn shall be minimal, limiting the resistance of the circuit (Section 8.5.3) to 1 ohm and the CONTRACTOR shall submit the solution adopted, with a technico-economic assessment, to the COMPANY for approval.

9.1.2 General characteristics

The equipment shall be suited to the chosen location (inside a building or outside, under shelter or not) which shall in all cases be situated outside of any hazardous area and accessible at all times.

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

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

- Inside the cubicle, with the components insulated to avoid any contact or short circuit when worked on by personnel
- If necessary, in a mineral oil-filled tank, fitted in the upper part with a filling hole, a thermometer and an oil sight gauge, and in the bottom part with a drain valve (outdoor transformer-rectifier for desert areas).

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

For the set of gas thermo-generators, the capacity of the gas tanks shall be calculated for a duration of five (5) consecutive days of shutdown when fed from a gas pipeline and one (1) month between two refilling when fed externally.

9.1.3 Breakers for ON/OFF potential measurements

Each of the DC current sources necessary for ensuring cathodic protection of the pipeline shall be equipped with a breaker allowing ON/OFF potential measurements. The type and characteristics of breakers shall be adapted to the maximum nominal current output. When more than two CP stations are necessary, breakers shall be such that precise synchronisation of ON/OFF cycles is ensured.

9.1.4 Spare parts

The transformer rectifiers and self-powered DC sources shall be supplied ready to operate and with the spare parts needed for the commissioning period.

The CONTRACTOR shall submit a list of spare parts for two years operation to the COMPANY for approval.

9.1.5 Testing

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

- A visual inspection of conformity
- A trial at nominal power and at the maximum temperature of the site with a check on heating
- A check on the wiring diagram and the operating manual provided.

For self-powered DC sources, the CONTRACTOR shall submit a quality inspection plan to the COMPANY, accompanied by inspection and test procedures, for approval.

9.2 Impressed current anodes

This section gives the quality requirements for the most commonly used anodes: high silicon iron (Fe/Si) with or without added chromium.

For the other types, such as scrap steel, magnetite (Fe₃O₄) and mixed metal oxides on titanium substrate, the CONTRACTOR shall submit a data sheet with sufficient detail to justify the choice to the COMPANY for approval. Qualification of the equipment proposed may be required by the COMPANY.

The anodes shall be supplied ready for installation, delivered preconditioned or not in a backfill column (canister).

9.2.1 Alloy composition

The alloy composition of Fe/Si anodes shall comply with **BS 1591** and meet the following grades:

Element	Grade with chromium	Normal grade
Si	14.25 - 15.25%	13.50%
Mn	0.50% nominal	0.75%
C	0.70 - 0.80%	0.95%
Cr	4.0 - 5.0%	-
S	0.60% max.	0.75%
P	0.10% max.	0.25% max.

9.2.2 Backfill composition and preconditioning

9.2.2.1 Backfill

The backfill comprises 99 grade petroleum coke breeze, containing at least 98% carbon, with a particle size ranging from 0.2 to 0.7 mm and a maximum resistivity of 1 Ω.cm.

This type of backfill shall be used where there is no water table influence, because of a specific weight below 1 kg/dm³ and no soil improvement around the anodes resulting from a high soil resistivity.

Where there is influence from water tables or soil improvement, the backfill may be:

- Composed of bentonite (25%), gypsum (70%) and sodium sulphate (5%) mixed with water to form a compact mud
- Recovery steel angular shot with a particle size less than 1 mm.

9.2.2.2 Preconditioning

Anodes supplied preconditioning (Fe/Si or magnetite) shall be factory centred inside a closed steel cylindrical "canister" made of spiral wound galvanized sheet steel with a minimum thickness of 0.5 mm.

The dimensions of the canister shall be adapted to the dimensions of the anode, within the following limits:

- External diameter at least three times that of the anode
- Length at least 1.3 times that of the anode.

The end of the canister with the cable entry shall be fitted with a cable gland and a lifting handle, to avoid having to handle by the cable.

The backfill surrounding the anode shall be petroleum coke breeze based and compacted when installed.

9.2.3 Cables

The anode shall be supplied with a 3 m length of PE/PVC (XLPE/PVC) double insulated cable with a cross-sectional area of 1 x 16 mm², unless otherwise stipulated in the job specification.

The cable shall be connected to the core of the anode located at the bottom of a cavity provided for this purpose, the relevant connection being carefully sealed and insulated with a two part, chlorine-resistant epoxy compound.

A suitable sleeve or heat-shrinkable cap shall be provided to reinforce the insulation and seal tightness of the connection and the cable at the head of the anode.

9.2.4 Quality control

The CONTRACTOR shall deliver the anodes together with the following documentation:

- Chemical analysis certificates of the castings
- Certificate of conformity of the cable-to-anode core connection, specifying that the connection resistance is no greater than 0.06 Ω
- A test certificate of the mechanical resistance of the connection, carried out on 5% of the anodes ordered, and for which the minimum required value is 200 kg for Fe/Si anodes, with or without chromium
- A visual and dimensional inspection certificate.

9.3 Sacrificial anodes

This section mainly concerns magnesium alloy anodes.

The other types, such as zinc and indium activated aluminium, are normally not used to protect the buried structures. However, zinc ribbon may be used for the cathodic protection of the pipeline section inside the annular space of the steel casing and the zinc anodes to provide an earthing system.

The requirements for alloy composition, quality, inspection and performance shall be defined in **GS COR 201** applicable to any supply of sacrificial anodes.

The sacrificial anodes may be used bare, where soil resistivity is below 10 Ω .m, but preferably preconditioned in a regulating compound or backfill as defined below.

9.3.1 Backfill

The backfill used with magnesium and zinc anodes shall comply with the following composition requirements:

- 75% gypsum ($\text{CaSO}_4 - 2 \text{H}_2\text{O}$)
- 20% bentonite
- 5% sodium sulphate (Na_2SO_4)

The weight of backfill surrounding each anode shall be at least equal to the net weight of the anode and be contained in a cotton bag or a metal canister as defined in Section 9.2.2.

9.3.2 Quality control

In the proposal, the CONTRACTOR shall specify:

- The alloy composition and net weight of the anode
- The composition and weight of backfill
- The dimensions of the anode and backfill
- The type, section and length of the anode cable (see Section 9.4).

9.4 Cables

Four types of cable shall normally be used to connect the cathodic protection system and the earthing circuit:

- Main circuits (anodic and cathodic)
- Anode connection
- Earthing
- Measurements.

These cables shall comply with the regulatory requirements.

9.4.1 Main circuit cables

For an impressed current system, these cables shall include the links between the anode ground bed and the positive pole of the rectifier, or of an intermediate junction box and, on the other side, between the protected structure and the negative pole of the rectifier, if necessary through a test/junction box where several structures are involved.

For a sacrificial anode system, these cables shall include the bonding links between the anode ground bed and a test/junction box and, on the other side, between the protected structure and the same box.

The cables shall be single core, flexible or semi-rigid copper cables, with double insulation (PE/PVC or PVC/PVC).

For safety, the anodic circuit shall prevent accidental cut-out by providing a loop, or by duplicating the link to maintain the anode power feed.

The cross-sectional area of the main cables shall be defined according to the maximum current, and be at least equal to 16 mm^2 . The cross-sectional area may be greater if the anodic mass or

structures to be protected are distant from the rectifier (30 to 100 m or more) in order to minimize voltage drop in the cable.

9.4.2 Anode connecting cables

The anodes may be connected either to the main anodic circuit or individually and directly to the positive pole of the transformer-rectifier, or to a junction box.

In the first case, the length of anode cable shall be as short as possible, but not less than 2 m. In the second case, the cable section shall be determined to keep the voltage drop in the cables as low as possible, and at most equal to the permitted limit.

9.4.3 Earthing cables

Unless otherwise indicated in the regulation, the earthing may be provided by bare or insulated copper cables, semi-rigid and rated according to the standard concerning low voltage electrical installations.

9.4.4 Measurement cables

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

9.5 Cable connection accessories

These accessories are for branch connecting anode cables to the positive main cable. At the point of connection, the insulation of the main cable is removed over 4 to 5 cm to allow connection of the anode cable, itself stripped over 2 to 3 cm, by clip-screwed or crimped connector. The main cable must not under any circumstances be cut.

After checking mechanical strength and electrical continuity, the connection shall be insulated by a cold cure epoxy resin into a mould previously placed around the joint and sealed at each end.

The connection shall not be handled until the resin is completely cured as per the data sheet of this resin.

9.6 Junction boxes

These boxes are mainly as a marshalling point for anodic or cathodic cables at DC current sources, and shall preferably be located outside of hazardous areas so that they can always be accessed when live.

Consequently, unless there is a specific situation justified by the COMPANY, reinforced safety boxes shall not be required. However, they shall provide a minimum of protection against shocks and the ingress of water, whether made of insulating material (PVC, polycarbonate, etc.) or metal (steel, cast aluminium, stainless steel), and of type of:

- IP 55/IK 08 for outdoor locations
- IP 41 for indoor locations.

The internal equipment, such as the number and sizes of copper strips, cable terminals, resistors and any other particular components, shall be defined in the detailed study.

The junction box, internal equipment and support structure shall be selected and/or treated to withstand the specific climatic conditions.

The cables shall be easy to disconnect for measurements and their entry into the junction box shall be via cable gland of metal or insulating material, or via support pipe according to the type of box selected.

9.7 Monitoring equipment

9.7.1 Potential test points

Test points shall be provided along the pipeline route in the following cases:

- At road and rail crossings and for pipelines within the casing
- At the point of intersection of one or more pipelines
- In sections where several pipelines run in parallel
- To measure current circulating in the pipeline
- At insulating joints
- At high voltage line crossing points with particular devices
- At all other points defined in the detailed study.

Outside urban areas, these test points shall comprise a junction box, as defined in Section 9.6 according to the number of cables connected and the sizes of the internal accessories, or a 3" or 4" pipe:

- Made of rugged plastic or metal, in which the cables are located
- Provided with a lockable opening in the top part
- Internally fitted with an insulating plate located in front of the opening, supporting the equipment defined in the detailed study (terminals, shunt strips, resistors, diodes, surge diverters, etc.),

such that, the height above ground is at least 1.5 m and the other end protrudes 5 cm beyond the concrete base.

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

In urban areas, except within the fence and wall limit, these test points shall comprise a junction box as defined in Section 9.6, placed inside a concrete pit or vault.

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

9.7.2 Permanent reference electrodes

These electrodes are designed as a means of monitoring the effectiveness of the cathodic protection system, by measuring, either directly or via a remote monitoring system, the pipe-to-soil potential at the point at which they are located. If appropriate, they can provide a durable means of controlling a regulation device (see Section 9.1).

The electrolyte compound, comprising 1/3 bentonite and 2/3 copper sulphate, which replaces the gelatine of the portable electrode, shall be contained in a porous pot cylinder at least 100 mm in diameter and 200 mm high. The top part of the cylinder shall be closed with a cold cure hard mastic or equivalent.

The electrolytic copper cable, the length of which shall be defined in the detailed study of the system to allow direct connection to surface equipment, shall be stripped over about 1 m and spirally wound at the end located in the above compound.

The location and number of permanent reference electrodes shall be determined in the detailed study of the system by the CONTRACTOR. However, one electrode shall be provided at each:

- Impressed current source where there are stray currents
- Pipeline current test station along the route
- Test point, where the pipeline is buried more than 3 m deep
- Test point in urban areas and when the surface is asphalted or concreted
- Test point where the pipeline is weighted with concrete or protected by concrete slabs.

Before energizing, the permanent Cu-CuSO₄ electrodes shall be immersed in fresh water for at least 24 hours to ensure that the bentonitic compound is completely humidified.

The permanent reference electrode shall be assumed to be stable 72 hours after its total immersion.

9.7.3 Coupons

When appropriate, coupons allowing local ON/OFF measurements together with cathodic current density measurements shall be supplied and installed. This is especially required when stray or telluric currents have been identified. CONTRACTOR shall propose to the approval of COMPANY detailed information on the equipment proposed and the location of the coupons along the pipeline.

9.7.4 Current test points (by insulation resistance of pipeline)

Test points shall be provided along the pipeline route, every 10/15 km according to the pipeline length. Test points shall comprise four cables separated by 50 m minimum between two cables pairs and brought to the test point in order to check the overall resistance of the pipeline so that the current draw needed for this section can be calculated.

10. Installation

10.1 Impressed current DC sources

Indoor wall-mounted air-cooled transformer-rectifier sets shall be installed inside a technical building or shelter, and in a well ventilated place that is easily and permanently accessible.

For outdoor installation, it shall be located outside the perimeter of the hazardous area in accordance with safety regulation. If this is not possible, all of the components for adjustment, monitoring, protection and connection, including the cubicle, shall satisfy the requirements relating to electrical apparatus located in potentially explosive areas, as described in **GS ELE 079**.

Self-powered DC sources shall be located outside the hazardous area and within an enclosed area bounded by a fence, with the control and monitoring cubicles located either inside a shelter or under a canopy.

The layout shall be executed in accordance with the CONTRACTOR's instructions, drawn up in accordance with local regulatory requirements concerning low voltage electrical installations.

10.2 Junction boxes

The junction boxes shall be mounted on a metallic support (steel pipe or section) anchored in a concrete base.

Where cable entry is by cable glands, cables shall be routed up from the concrete base via cable tray used for fixing and protection purposes.

Through the concrete base, if there is no pipe support, the cables shall be protected in PVC sheathing of sufficient diameter to allow the cables to pass easily and, if necessary, accept additional cables.

10.3 Test points

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

The junction boxes, preferably mounted on pipe supports, shall be installed as defined in Section 10.2. The tubular test points shall be sealed in a concrete base.

In addition, the frequency of the test points shall be determined in accordance with the following requirements:

- One pipeline current measuring point:
 - Upstream and downstream from each impressed current source, except where an insulating joint electrically separates the two sections, or when there is only one section
 - Between two impressed current sources 5/6 km apart
 - At the junction between new and old or buried/underwater pipeline sections without insulating joint.
- One pipeline potential point every 1 to 2 km for a normal route and 0.5 to 1 km for urban areas.

In asphalted or concreted areas, regular access shall be provided through to the natural soil to allow the contact of a portable electrode near to or above the protected pipeline at the test point locations. These access points shall comprise a rigid PVC tube, 75 to 100 mm in diameter, extending to the surface and closed by a removable cap.

10.4 Cables

The positive and negative circuit cables, including those of the permanent reference electrodes, shall be buried to a depth of 0.8 m on a sand bed with a warning mesh placed 20 cm above, or laid in specially provided underground concrete or plastic ducting.

All cables shall be suitably tagged inside the cathodic protection equipment (transformer-rectifier, junction boxes, test points) and left unconnected to avoid over-voltage conditions during the work.

10.5 Cable connections on pipeline

The electrical resistance of the negative cable connection to the pipeline shall not cause a voltage drop detrimental to the effectiveness of the cathodic protection system.

This connection, located on the upper generatrix of the pipeline, may be executed:

- For buried links, by thermit welding or electrical discharge pin brazing directly on the pipeline or on a welded steel plate on the pipeline, depending on the steel characteristics.
- For buried or overhead links, by bolting to a welded steel plate (50 x 60 x 6 mm), with a 13 mm hole drilled in its centre. The bolts and nuts used to fix the cable lug shall be of brass or cadmium plated or galvanized steel.

In any case, the connection process has to be submitted for approval of the COMPANY.

Any buried connection shall be insulated from the surrounding electrolyte by a suitable mastic such as cold cure epoxy. The cable shall not be wound around the pipeline and shall be fixed to it at the top, by polyamide collars describing S about 0.5 m long.

Note: For good mechanical behaviour of the steel plate during handling, a rolled plate shall be inserted between pipeline and steel plate.

10.6 Permanent reference electrodes and coupons

10.6.1 Location

The number and location of the permanent reference electrodes and coupons shall be defined in the detailed study. They shall be positioned no more than 10 cm from the outer surface of the pipeline, either above the centre line of the pipe or on the side, at mid-axis.

10.6.2 Installation

The reference electrodes and coupons shall be placed in stone-free natural soil, compacted to remove any voids. They shall be laid vertically, to the required depth, within a PVC pipe, extending into a pit closed by a removable cover.

After laying, the reference electrodes and coupons shall be sprinkled with 20 to 30 litres water.

10.6.3 Checking

After laying and final backfilling the permanent electrode potential shall be checked relative to a calibrated portable reference electrode (Cu-CuSO₄ or calomel) positioned nearby.

10.7 Anodes

10.7.1 Sacrificial anodes

Except for particular cases, these anodes shall be supplied preconditioned in a non-hydrated regulating compound ("backfill"). Preferably, before layout, by immersion in fresh water, and in any case before backfilling, the anodes shall be soaked for 24 hours.

The anodes shall normally be located at a short distance from the protected pipeline, but shall satisfy the following minimal requirements:

- 2 to 3 m distance from the lateral generatrix of the pipeline
- Depth of 1 m minimum or three quarters of the pipeline diameter measured from the upper generatrix.

The anodes shall normally be laid horizontally in the bottom of the trench for a new pipeline. However, for an existing pipeline, and to limit the civil engineering work, the anodes may be installed vertically in a drilled hole.

The trench or drilling shall be perfectly backfilled after laying.

10.7.2 Impressed current anodes

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

- Soil resistivity
- Distance from the protected pipeline and other buried structures
- Land occupation of the anodic ground bed.

This means that it cannot be standardized for any protected pipeline.

However, the following criteria shall be observed:

- Anodes shall be laid in soil of the lowest possible resistivity
- The distance between the nearest anode and the nearer point of the pipeline shall be greater than 80 m for configuration 1 and 25 m for configuration 2 (see Section 8.5.3.2)
- A minimum distance of 80 m from nearby metallic structures, unless specific measures are undertaken to limit the anodic influence on such structures.

The detailed study shall define the land occupation of the anodic ground bed, the number and spacing between anodes, and the depth and routing of the cables.

For high soil resistivity situations, the anodic ground bed resistance calculation may lead to a length that is unsuited to the available land dimensions. The CONTRACTOR should then propose a soil improvement around the horizontally installed anode and the installation of a permanent watering system or several anodic ground beds.

For configuration 1, in dry land or dry seasons, the anodic ground bed shall be watered with 50 l of water per meter of trench before final backfilling. The backfilling shall be carried out after slight tamping of the backfill around the anodes, with all stones removed from the soil. Upon completion, each anodic ground bed location shall be marked at both ends and at ground level by a concrete or coloured plastic marker.

For vertical anodes in deep columns, the requirements of [NACE RP 0572](#) shall apply.

11. Commissioning

The commissioning of the cathodic protection system shall not take place until all the welding, insulation, wiring and civil engineering work has been completed on the protected pipeline and its surface installations.

A detailed schedule for commissioning, drawn up by the CONTRACTOR and including preliminary and final operations, shall be submitted to the COMPANY for approval.

11.1 Sacrificial anodes

The commissioning procedure shall entail:

- Measuring, before making any connections between cables and anodes, the free electrical status (E_n) relative to the soil of all structures, whether protected or not, and connected inside the junction boxes and test points, including permanent reference electrodes and anodes
- Connecting the cables and anodes to the protected pipeline inside the junction boxes or test points, with the variable resistor, if there is one on the anodic circuit, set to zero
- Measuring anode current output (I_a), with the variable resistor, if there is one, set to zero and then to its maximum value
- Measuring the new free electrical state (E) relative to the soil surrounding the pipeline, with the resistor, if there is one, still at its maximum value.

11.2 Impressed current

The commissioning procedure shall entail:

- Measuring, before making any connections between cables, the free electrical status (E_n) relative to the soil of all structures, whether protected or not, and connected inside the junction boxes and test points, including permanent reference electrodes
- Connecting all the cables inside the junction boxes and to the DC sources
- Checking out operation of each DC source:
 - Checking the power supply voltage and DC output voltage (U_o) off-load (0 to 100%)
 - Powering up and measuring DC characteristics (current I , voltage U and potential E at the drain point) for 25, 50 and 100% of nominal rating of the DC source.
- Adjustment to the minimum of each source to obtain the required protection level (E_p) at the points furthest from it.

11.3 Measurements after connection and adjustment

Any structure to which cathodic protection has been applied is subject to a polarization phase before a permanent protection level can be reached. After connecting the DC sources, the CONTRACTOR shall take preliminary readings (potentials and currents) to ensure that the system is fully operational and correctly adjusted (or under or over protection levels). During this phase, the remote monitoring system, if any, shall be tested.

The CONTRACTOR shall record all the results on data sheets, specific to the pipeline and the installation, drawn up for this purpose, for submission to the COMPANY.

11.3.1 Impressed current system

After these measurements at minimum setting, and a period of 48 hours, the CONTRACTOR shall take final readings of the operating parameters and the protection level (ON/OFF measurements) at the same points (portable reference electrode located at the same points).

If the upper level (E_p) is not achieved, the adjacent DC sources shall be re-adjusted to obtain a potential of between -950 and -1000 mV.

If the protection level at the least negative point is greater than the required limit (E_p), this may result in a lower setting on the same DC sources.

For a system controlled automatically, the CONTRACTOR shall set up the regulation parameters to maintain the protection level within the specified minimum-maximum range (E_p - E_I).

11.3.2 Sacrificial anodes

Final readings shall be taken by the CONTRACTOR as for the impressed current system. However, if the upper protection limit (E_p) is not reached, either the anode output current (I_a) shall be increased, if a variable resistor is available, or additional anodes shall be installed at the points concerned to obtain a potential of -950 mV.

If the protection level exceeds the lower limit (E_I), resulting in a detrimental overprotection either to the steel (embattlement) or to the coating or painting system (separation), the anode output current (I_a) shall be limited by the installation of a variable resistor, if there is not one already, or by increasing the resistance value, or by disconnecting some of the anodes.

11.3.3 Influence measurements

Whatever the type of cathodic protection system, contradictory influence measurements shall be proposed to the COMPANYS representing any metal structure that is crossed or run in parallel after final adjustment.

These potential measurements shall be used to determine whether there is any influence from the cathodic protection system:

- Or the pipeline on the existing structure, protected or otherwise
- Of the existing structure on the pipeline.

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

12. Routine inspections

A further series of measurements shall be performed in the first three to four months of operation after commissioning. The results shall then demonstrate the effectiveness of the cathodic protection system.

The subsequent schedule of routine inspections shall be drawn up by the CONTRACTOR at the request of the COMPANY.

13. Quality assurance procedures

13.1 General

At the beginning of the design, a Quality Plan must be drawn up by the CONTRACTOR, detailing all the actions related to the cathodic protection calculation, to the definition of the systems to install, to the provisioning, checking and reception of equipment, and the commissioning on site. These shall be described in detailed procedures.

All the calculations, systems, and materials used shall be approved by the COMPANY.

13.2 Equipment

In the technical part, characteristics and references of some materials and apparatus used for the cathodic protection systems shall be specified as:

- Impressed current DC sources, impressed current and sacrificial anodes, insulating joints, safety devices, reference electrodes and other measurement devices, cables, junction boxes receptionned in plant by the CONTRACTOR
- Painting and coating
- Wiring plans.

13.3 Technical file

The technical file submitted by the CONTRACTOR at the end of the work shall include:

- The characteristics of the pipeline to protect
- The detailed calculations of the cathodic protection
- The systems related to the installation
- The data sheets and test certificates of the materials
- The detailed drawings of the different systems
- The values obtained during the commissioning.