



Exploration & Production

GENERAL SPECIFICATION

CORROSION

GS EP COR 112

External cathodic protection of Onshore deep well casing

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1. Scope

This specification covers the rules applicable to cathodic protection systems for the anticorrosion protection ([ISO 8044](#)) of the external surface of deep well casing used for hydrocarbon, gas or water deep wells. It covers the minimum requirements for the design, installation and commissioning of such external cathodic protection systems.

Should such well casing be located in restricted areas such as plants, stations, treatment or storage centres, cathodic protection system shall be designed considering not only this specification but also General Specification [GS EP COR 111](#) related to cathodic protection of onshore facilities.

Similarly, possible interferences with buried flowlines or pipelines shall be studied according to General Specification [GS EP COR 110](#) related to cathodic protection of pipelines.

2. Reference documents

The reference documents listed below form an integral part of this General Specification. In the case of conflict between this General Specification and the requirements of these documents, the requirements of this General Specification shall apply. Similarly, in the case of conflict between the documents below, [NACE RP 0186](#) shall apply before [EN 15112](#). 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.

Standards

Reference	Title
BS 1377 (Parts 3; 9)	Methods of tests for soils for civil engineering purposes – (Parts 3; 9)
BS 7361-1	Cathodic protection – Part 1: Code of Practice for land and marine applications
EN 13509	Cathodic protection measurement techniques
EN 14505	Cathodic protection of complex structures
EN 15112	External cathodic protection of well casings
EN 12954	Cathodic protection of buried or immersed metallic structures - General principles
IEC 227	Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V
IEC 502	Characteristics and constitution of cables
IEC 529	Degrees of protection provided by enclosures (IP code)
IEC 79	Electrical apparatus for explosive gas atmospheres
ISO 8044	Corrosion of metals and alloys - Basic terms and definition

**Professional Documents**

Reference	Title
NACE RP 0186	Application of cathodic protection for external surfaces of steel well casings
NACE TM 0497	Measurement techniques related to criteria for cathodic protection on underground or submerged metallic piping systems
NACE RP 0169	Control of external corrosion on underground or submerged metallic piping systems
NACE RP 0177	Mitigation of alternating current and lightning effects on metallic structures and corrosion control 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

Regulations

Reference	Title
Not applicable	

Codes

Reference	Title
Not applicable	

Other documents

Reference	Title
Not applicable	

**Total General Specifications**

Reference	Title
GS EP COR 110	Design of cathodic protection of buried pipelines
GS EP COR 111	External cathodic protection of onshore facilities
GS EP COR 210	Monolithic insulating joints
GS EP ELE 031	Design of earthing and bonding systems
GS EP ELE 051	Design and installation of lightning protection
GS EP ELE 079	Electrical apparatus for explosive gas atmosphere
GS EP ELE 141	Power Transformers
GS EP PLR 420	Site welding of carbon steel pipelines to API 1104 and DNV-OS-F101 (sweet service)
GS EP PLR 421	Site welding of carbon steel pipelines to API 1104 and DNV-OS-F101 (mild, intermediate and severe sour service)

3. General requirements

3.1 Qualification and Certification

Design of cathodic protection systems to be installed on facilities shall be carried out exclusively by competent specialised personnel. Qualification of each of the specialists working for such a design shall be demonstrated by Contractor to Company before commencement of the work. Therefore the verification of the formal Certification of the individuals shall comply with the following requirements:

- Conventional design work, supervision of installation and pre-commissioning to be carried out by certified personnel at level 2 for all Certification schemes except for NACE International where it shall be level 3
- Complex design work, verification or commissioning to be carried out by certified personnel at level 3 for all Certification schemes except for NACE International where it shall be level 4.

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

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

3.2 Sub-contractors

If Contractor intends to subcontract all or part of the scope of work, its sub-contractor shall be approved by Company.



In any case, Contractor remains fully responsible for the successful completion of the cathodic protection project.

In the case of complex installations or for any reason calling for the simultaneous intervention of several Contractors, Contractor shall ensure coordination and compatibility of the various cathodic protection studies, the standardisation of equipment, interface management, the preparation of an overall start-up and commissioning plan, and the issue 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 collection of all documents and information with regards to the design of the wells to be protected, and the characteristics which are likely to influence the design of the cathodic protection system, such as but not limited to:
 - Drawing of geological cross section of the field
 - Detailed map showing wells location
 - Work Over schedule
 - Wells summary with all necessary information (type, age, depth, location)
 - Quality of cementing
 - Well integrity
 - Casing drawings for a selection of representative wells
 - Report on wells & flowline cathodic protection status.
- The site survey which shall collect all relevant information and measurements required for the cathodic protection design (see § 4).
- The collection of all documents and information with regards to the work area: presence of nearby metallic structures whether cathodically protected or not, presence of works likely to generate stray currents, presence of high voltage cables or transmission lines, electric power stations, transformer stations, etc., which may impact cathodic protection efficiency or, if faulty, may damage the installation.
- The collection of all information with regards to the availability of electrical power for the supply of cathodic protection installations.
- The preparation of a detailed report comprising:
 - An analysis of all information gathered and measurements taken, and an estimate of corrosion risks
 - Justified design hypotheses
 - The list, areas and nature of the structures to be protected and considered as DC consumers

- The technical requirements to be followed by other disciplines (civil works, piping, electricity) for electrical continuity and/or discontinuity of metallic structures
- A technical and cost evaluation of power supply options (solar, TEG, AC availability, etc.)
- 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 20 years minimum
- A list of materials, including assembly accessories, and the corresponding technical specifications
- A list of potential suppliers
- Schematics of the proposed system
- Detailed equipment drawings.
- Detailed installation drawings, indicating:
 - The location of insulating joints if any
 - Electrical bonding or insulation to be installed
 - The layout of different types of equipment and the relevant installation procedure
 - Wiring diagram for electrical equipment.
- Installation instructions 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 items
 - Insulations between items protected by different systems
 - Insulations between items protected by the same system, which must be separated temporarily for various operational reasons
 - Influence correctors between the work to be protected and neighbouring works
 - Reference electrode installations at fixed points.
- Instructions for checks and inspection during the works and testing upon completion during start-up.

The location of DC power equipment (rectifier, drain point, current distribution, anodes, interconnection and insulating joint boxes) shall be outside of hazardous areas to allow permanent access.

3.3.2 Equipment supply

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

Contractor shall also supply all spare parts which are required for start-up of the installation.



Contractor shall make all necessary arrangements with Vendor to allow Company access at all times to the workshops during manufacturing to check and witness:

- Manufacturing progress
- That the equipment conforms to the specifications
- Testing.

A provisional manufacturing schedule shall be handed to Company so that inspections can be planned.

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

The final manufacturing report shall consist of:

- A detailed description of the equipment
- The Vendor's drawings and the operating and maintenance instructions
- The as built drawings
- The equipment list with Vendor's addresses
- The list of spare parts for two years operation, with complete references
- The operating procedures
- The FAT reports.

4. Site survey

The objective of the pre-design site survey is to collect necessary information, and to perform sufficient testing to enable the design to be prepared ([BS 1377 – Parts 3; 9](#)).

The field measurements to be performed in this site survey include:

- E-Log I testing
- Soil resistivity measurements
- Stray current testing of foreign structures
- Testing of isolation joints
- CPET Logging with and without CP current applied
- Current drain from flowlines connected to wellheads.

It shall be noted that some of those measurements are achievable only for existing casings. In case of new installation, some of the tests will be postponed after the first well casing installation has been completed.

4.1 E-Log I Testing

The E-Log I method is used to estimate the minimum current required to cathodically protect well casings. Proper analysis of the E-Log I test results provides a mean to evaluate the well casing polarization as a result of the application of an impressed DC current. The procedures



involves applying a DC current to a well casing and monitoring the "Instant OFF" casing-to-soil potential as the applied current is increased in even intervals.

It is important to consider aboveground measurement as not fully representative: current break given by E-Log I does not depend on well depth, but depends mainly on surface resistivity. Consequently the information given by E-Log I testing corresponds to the shallow part of the well only.

4.2 Soil resistivity measurements

Soil resistivity shall be measured by the four aligned and equidistant pins method (Wenner's method), or by the Schlumberger method or preferably by inductive electromagnetic technique, at representative locations and at pre-selected points for the location of anodes.

If soil resistivity survey results are supplied to Contractor, Contractor may proceed to check them at random and at selected points for location of the anodes.

Those resistivity measurements shall also include Sabkha areas which shall be precisely located.

4.3 Interference Testing on Foreign Structures

Usually wells are located in close proximity to existing plant facilities. Testing is carried out to determine the impact of the operation of an impressed current system for the well casing on foreign structures in the area. Interference testing shall be carried out in conjunction with E-Log I testing.

4.4 CPET Logging

Corrosion Protection Evaluation Tool (CPET) logs provide valuable information which is used to determine the magnitude of cathodic protection current required to mitigate the natural galvanic corrosion occurring on the external surface of a well casing. CPET logs are also used for assessing subsurface stray current interference problems which may exist on a well casing.

CPET logging is to be carried out in conjunction with a previously scheduled well work-over. For this investigation, it is recommended that CPET logging using the Schlumberger tool be carried out on a few representative wells.

The CPET Log involves multiple tests as follows:

- Static without any CP current applied to the casing
- With CP current applied as per E-Log I results
- Additional run with increase of CP current in locations where E-Log I test current is not sufficient to eliminate anodic areas.

4.5 Current Flow in Wellhead Flowlines

The current return through the flowlines connected to the wellheads should be measured during E-Log I and CPET testing and before the temporary CP system is energized. Current flow shall also be monitored after the CP system is energized. The most appropriate tool to measure such current is the Swain Clamp Meter.



5. Design and installation of a cathodic protection system

5.1 CP Configuration

One approach used for protection of well casings is to protect multiple well casings with a single impressed current system. This scheme typically involves using associated flowlines as the negative return path for the CP current. This concept may be used if the configuration of the flowlines allows the pipelines to be easily isolated at central locations. In addition this “cluster” configuration requires well casings in very similar conditions in terms of age, cementation, and depth. Otherwise each wellhead shall be electrically isolated from associated flowlines (see § 5.2).

If these requirements can not be fulfilled, an independent impressed current system has to be installed for each well casing.

More generally, the CP design shall be in accordance with [EN 12954](#), [EN 14505](#), [NACE RP 0169](#) and [BS 7361-1](#).

5.2 Electrical Insulation

Under certain conditions, it is desirable to electrically insulate the well casing from the flowline and to provide a bond box across the insulator to control current flow to both the flow line and well casing.

This approach allows distributing protective current between the well casing and the flowlines, while at the same time, overcoming the interference effects with the flowline and nearby well casings when only insulated well casings are protected. When such option is chosen, particular care shall be given to joint design (see also § 5.5).

The alternative option is to integrate the flowlines with the well casings. The flowlines will benefit from the well casing CP system. Impact on current requirement is usually reasonable but it shall be nonetheless taken into account.

This second solution shall always be preferred unless a clear justification for isolation is given.

5.3 Groundbed Configuration

A low groundbed-to-earth resistance is essential to increase the efficiency of the CP system and decrease the power requirements. Consequently, for high resistivity shallow grounds, deep anode groundbeds shall be used, with the anodes positioned in the upper sub-surface aquifers.

In Sabkha area, although resistivity is low, deep groundbeds shall be drilled until the water table is encountered, to avoid most of the current being drained to structures buried in surface layers.

To provide uniform current distribution to the well casing, it is essential that the groundbed be located electrically remote from the casing. The distance to achieve electrical remoteness is a function of various factors including soil resistivity but is typically between 150 to 200 meters.

5.4 Current and voltage requirement

5.4.1 Current

The following design current densities shall be taken as a basis for current requirement calculations:

Table 1 - Typical current densities

Description	Typical resistivity	Quality of cementation	Current densities (mA/m ²) for bare casing
Surface ground	Hundreds ohms.m		1
	Few ohms.m (Sabkha)		100
Shallow water table (groundbed)	Few ohms.m	Good	25
		Bad	75
Aquifer	Few ohms.m	Good	5
		Bad	20
Dry layers (clays or others)	Few ohms.m	Good	1
		Bad	5
	Hundreds ohms.m		1

This table is given for information only. A study shall be performed on a case-by-case basis, as the age of the well cannot be taken into account in this table. As a first approach, age influence can be compared to the quality of cementation: the older the well, the more current it requires.

If a very high resistive layer is present (hundreds of ohm.m) without any aquifer layer below, the design should consider that the current won't cross this layer. Thus only the upper part of the well will be considered for current requirement. As a consequence, only this upper part will be cathodically protected.

If no lithology information is available, the design shall be based on an average current density of **10 mA/m²**. This current density shall apply to the well casing only, thus it does not take into account possible losses due to current drain on the flowlines.

To determine the total current requirement (I), Contractor shall calculate which areas of the casing are in each layer, and apply to each one the relevant current density.

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

$$I_n \geq 1.25 I$$

5.4.2 Voltage

The output voltage (U in V) from the DC source (normally a transformer/rectifier) 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:

$$U \geq 1.2 RI$$



With:

I: Total current required (A)

R: Maximum overall resistance (Ω)

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

5.4.3 Calculating circuit resistance

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

$$R = R_{an} + R_{ca} + R_{lc}$$

With:

R_{an} : Resistance of the anodic groundbed relative to the ground (Ω)

R_{ca} : Resistance of the anode and cathode connecting cables (Ω)

R_{lc} : Leakage resistance of the casing relative to remote earth (Ω)

Note: Resistance of anode to the backfill is considered as negligible.

5.4.3.1 Horizontal anodes laid in a continuous backfill bed

The anode resistance (R_a) relative to the natural ground is calculated using Dwight's formula:

$$R_a = \frac{0.00159 \cdot \rho}{L} \left[\ln \left(\frac{4L^2 + 4L\sqrt{h^2 + L^2}}{d \cdot h} \right) + \frac{h}{L} - \frac{\sqrt{h^2 + L^2}}{L} - 1 \right]$$

With:

ρ : Resistivity of the ground ($\Omega \cdot \text{cm}$)

L: Length of the backfill (m)

d: Equivalent diameter of the backfill section (m)

h: Twice the depth to the centre line of the anodes and the backfill (m)

The overall resistance is then:

$$R_{an} = \frac{(R_a \times f)}{N}$$

With:

f: Anode interaction coefficient

N: Number of anodes

5.4.3.2 Individual (or string) anode, or multiple anodes in parallel in a backfill column

The unit resistance of the anodes (R_a) relative to the natural soil is calculated using Dwight's formula:

$$R_a = \left(\frac{\rho}{2\pi L} \right) \left[\ln \left(\frac{8L}{d} \right) - 1 \right]$$

With:

- ρ : Resistivity of soil ($\Omega.m$)
- L: Length of the backfill column (m)
- d: Diameter of the backfill column (m)

The overall resistance is then:

$$R_{an} = \left[\frac{(R_a \cdot f)}{N} \right]$$

With:

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

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

$$f = 1 + \frac{\left[\left(\frac{2L}{e} \right) \cdot \ln(0.656N) \right]}{\left[\ln\left(\frac{8L}{d} \right) - 1 \right]}$$

With:

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

Note: For deep well groundbed (single wire or string anodes), the resistance shall be calculated considering the overall external dimensions of the backfill column only.

5.4.3.3 Cable resistance

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

$$R_{ca} = \rho_o \cdot \left(\frac{l_c}{S_c} \right)$$

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)



5.4.3.4 Leakage resistance relative to remote earth

Unless justified by a specific calculation which shall be approved by Company, the leakage resistance of the coated structure relative to remote earth is calculated from the following formula:

$$R_{lc} = \frac{R_f}{S_b}$$

With:

- R_f : Faraday resistance of steel, taken equal to 5 ohm.m² at 10 ohm.m electrolyte resistivity (proportional for higher resistivity)
- S_b : Surface of bare steel

Important remark: A small difference in circuit resistance might impact notably the cost of the power supply, especially for solar systems. Consequently, site testing will be preferred to theoretical calculations to determine which circuit resistance shall be. It may be necessary to drill some anode groundbed to check the theoretical calculations during detailed engineering phase.

5.5 Insulating joints

If insulating joints are installed between well heads and flowlines, they shall fulfil the following requirement:

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

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

When determining the location of insulating joints, 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 or in non-floodable manholes, on a straight section of the pipe, 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.

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 pipe diameter. The length to be internally coated shall be calculated by Contractor and shall be submitted to the Company for approval. The pup piece on the unprotected side of the insulating joint shall not be coated.

Note: On sites that are subject to frequent lightning (keraunic number normally over 21), the Contractor shall install safety devices on insulating joint such as surge diverters or polarization cells, which shall remain operational without requiring constant attention.

Contractor shall submit the selected device (or devices) to Company for approval, in accordance with **GS EP ELE 051** and **NACE RP 0177**.



5.6 Casing coating

For new well casings, coating of the first hundreds meters shall be used whenever possible in order to suppress the need for installing insulating joint, or for one dedicated cathodic protection system for each well. Cluster CP configuration shall be adopted for the design (see § 5.1) and no insulating joint shall be installed (see § 5.2).

Coating shall be FBE and shall be manufactured according to **GS EP COR 222**. Current density for CP sizing shall be **1 mA/m²** for all coated surface.

6. Equipment

6.1 Power supply

6.1.1 Transformer-rectifiers

Selection of materials and installation for impressed current stations shall refer to **GS EP ELE 141** and be compliant with IEC international standards listed in Section 2 of the present specification.

Transformer-rectifiers shall operate as permanent generators connected to the circuit comprising the anode ground bed and the structure 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) operating control may be accepted on a case-by-case basis for specific purpose, with Company approval based.

Cooling shall be of the air cooled type (natural or forced convection), unless otherwise stipulated, e.g. for outdoor installations in corrosive environments, for which an oil cooled type should be preferred.

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.

Control, regulation and protection devices shall be installed inside the cubicle and accessible. The control of DC output can be either manual or automatic (variac only).

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

- Inside the cubicle, with components electrically 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 desertic areas).

6.1.2 Solar unit

A standard solar power system with battery storage is recommended for single well installations where AC power is not available or where the distance to extend existing AC power is not economical.



The solar power system shall be specifically designed to meet the requirements of the project. The solar power supplies shall consist of the following major components:

- Solar Array (Photovoltaic Array)
- Storage Batteries and Enclosure
- Battery Charge Controller
- Cathodic Protection/Output Controller
- Power Distribution Panel
- Instrumentation including Indication Lights, Meters and Signals
- Capability for Connection to Remote Monitoring or SCADA System
- Support Structure (adjustable) for Solar Panels.

The battery bank shall consist of flooded lead-acid gel battery modules electrically connected to deliver a nominal output voltage of 12 or 24 volts. The batteries shall have a proven track record in harsh desertic environments and the design shall be based on a capacity de-rated for 60 degree C ambient temperatures. The battery bank shall provide 2-3 days autonomy at 80% Depth of Discharge, under “no sun” conditions.

6.1.3 Others

Other power supply units (TEG, Diesel, etc.) should be study on a case by case basis.

6.1.4 Spare parts

The power supply units shall be supplied ready to operate and with the spare parts needed for the commissioning period.

Contractor shall submit a list of spare parts for two years operation to Company for approval.

6.1.5 Testing

Each power supply units shall be the subject of a Factory Acceptance Test (FAT) witnessed by a Company representative. This FAT shall include at least:

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

6.2 Impressed current anodes

6.2.1 Anodic system

Tubular titanium/MMO anodes are recommended. MMO anodes are dimensionally stable, are not subject to any significant variation in shape/length, and have a proven track record. There is negligible consumption of the titanium base material with time, which provides a constant DC output, constant resistance, and long operating life.

The anodes shall be backfilled with petroleum grade coke breeze.

6.2.2 Backfill composition and preconditioning

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 25 $\Omega \cdot \text{cm}$.

This type of backfill shall not be used where there is water table influence, because of a specific weight below 1 kg/dm^3 .

When there is influence from water tables the backfill may be:

- Installed in a geotextile packing containing coke breeze and anodes
- Otherwise composed of bentonite (25%), gypsum (70%) and sodium sulphate (5%) mixed with water to form a compact mud. In this case, the lack of beneficial effect of coke breeze on the anodic reaction shall be taken into account in defining the anode lifetime.

The backfill shall be inserted around the anode in a vertical steel casing.

6.2.3 Cables

The anode shall be supplied with HMWPE or PVDF/HMWPE double insulated cable in case of chlorite containing environment, with a cross-sectional area of 16 mm^2 minimum, 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.

6.2.4 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 visual and dimensional inspection certificate.

6.2.5 Main circuit cables

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.

The cables shall be single core, flexible or semi-rigid copper cables, with double insulation (XLPE/PVC or PVC/PVC), in accordance with [IEC 502](#) and [IEC 227](#).

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 delivered, 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 m or more) in order to minimize voltage drop in the cable.

6.2.6 Anode connection 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 cable resistance shall be equal to 0.1 ohm.

6.2.7 Measurement cables

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

6.2.8 Cable connection accessories

These accessories are for 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 the resin manufacturer.

6.3 Junction boxes

These boxes are for connecting anodic or cathodic cables at DC current sources, and shall preferably be located outside of hazardous areas so that they can be accessed at any time. If this is not possible, the equipment shall comply with [GS EP ELE 079](#) and [IEC 79](#).

When adjustable resistors are installed, the enclosure shall be large and ventilated enough to dissipate the produced heat. Calculation of resistor characteristics and enclosure size shall be submitted to Company for approval.

Consequently, unless there is a specific case, reinforced safety boxes shall not be required. However, junction boxes shall provide a minimum of protection against shocks and ingress of water, and be of the following type ([IEC 529](#)):

- IP 55/IK 08 for outdoor locations
- IP 31 for indoor locations.

The junction box, internal equipment and support structure shall 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 made of metal or insulating material, or via a pipe duct.



6.4 Monitoring equipment

6.4.1 Permanent reference electrodes

6.4.1.1 Number and location

As a first approach, only a few permanent reference electrodes should be installed at specific locations to allow checking of the potentials with time, which will give enough information in case of significant potential changes in the field.

The option to install one reference electrode for each well will be studied by Contractor and shall be submitted for Company approval.

6.4.1.2 Characteristics

The characteristics of the electrode shall fulfil the following requirements:

The electrolyte compound, comprising 1/3 bentonite and 2/3 copper sulphate, which replaces the gel of portable electrodes, shall be contained in a porous cylindrical pot at least 50 mm in diameter and 150 mm high. The top part of the cylinder shall be closed with a cold cure hard mastic or equivalent.

The electrolytic copper cable, which shall allow direct connection to surface equipment, shall be stripped over about 1 m and spirally wound at the end. Pure electrolytic copper shall be used.

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.

6.4.2 Current interrupter

It is not recommended to install permanent current interrupters on power supply.

However, a few portable GPS synchronized current interrupters shall be procured.

6.4.3 Remote monitoring

The installation of a remote monitoring system is recommended. The system should have a minimum of 8 channels for monitoring and control of various parameters including:

- DC voltage output of CP load
- DC current output of CP load
- DC voltage output of battery charging load
- DC current output of battery charging load
- "On" casing potential if reference electrode is fitted
- Battery charging status
- Battery temperature
- General fault alarm
- Door open alarm.



7. Installation

7.1 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 location that is easily and permanently accessible.

For outdoor installation, they shall be located outside hazardous areas.

Self-powered DC sources shall be located outside hazardous areas and within a fenced area, with the control and monitoring cubicles located either inside a shelter or under a canopy.

Each impressed current DC source shall be electrically protected by an earthing system in accordance with **GS EP ELE 031**.

7.2 Anodes

The distance between the anode groundbed and the well head shall be 100 m as a minimum.

For vertical anodes in deep columns, the requirements of **NACE RP 0572** shall apply. Particularly, the titanium anodes will be installed in 250 mm to 300 mm diameter bore holes drilled to a depth sufficient to ensure that the top anode is permanently below the upper level of the sub-surface aquifer.

7.3 Junction boxes

Junction boxes shall be mounted on a metallic support anchored in a concrete base.

Where cable entry is by cable glands, cables shall be routed from the concrete base to the junction box via cable trays.

Through the concrete base, the cables shall be protected as a minimum in PVC ducts of sufficient diameter to allow the cables to pass easily and, if necessary, accept additional cables.

If metallic junction boxes are used, in order to minimize any safety issues to the personnel due to electrical shock, its suitable grounding system(s) shall be installed. CONTRATOR shall provide detailed installation drawings of the grounding system for Company approval (in accordance with **GS EP ELE 031**).

7.4 Cables

Where possible, the DC power and test cables shall use the main cables routes. 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 cathodic protection equipment (transformer-rectifier, junction boxes, test points) and left unconnected to avoid over-voltage during installation works.

7.5 Cable connections

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



Connection may be executed:

- By thermit welding or electrical discharge pin brazing directly on the structure or on a welded steel plate, depending on the steel characteristics
- 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 made of brass or galvanized steel or shall be cadmium plated.

In any case, the choice to use or not a doubler plate, and the welding process for the connection have to be fully compliant with General Specification **GS EP PLR 420** (sweet service) and **GS EP PLR 421** (sour service).

Any buried connection shall be insulated from the surrounding soil by a suitable mastic such as cold cure epoxy. Each cable shall be secured on top of pipe by means of plastic collars with a 0.5 m free over length, without any turn around the collar.

7.6 Permanent reference electrodes

7.6.1 Installation

The reference electrodes shall be placed in stone-free natural soil, compacted to remove any voids. They shall be laid horizontally to the required depth. After laying, the reference electrodes shall be sprinkled with 20 to 30 litres water.

7.6.2 Checking

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

8. Commissioning

8.1 Protection criteria

The protection criteria shall be the application of the specified magnitude of current to the well casing. The cathodic protection system shall be adjusted to achieve the current which will be defined during design. This will be measured by subtracting the current return from the flowline (as measured with a clamp-on ammeter) from the total current output of the power supply.

8.2 Commissioning procedure

A commissioning procedure shall be prepared and submitted for Company approval.

The commissioning of each of the cathodic protection systems shall not take place until all the welding, insulation, wiring and civil engineering works have been completed.

A detailed schedule for commissioning, including preliminary and final operations, shall be submitted to Company for approval.

The commissioning itself shall be attended by Company representatives including personnel responsible for the maintenance of the system(s) in the future.

The commissioning procedure shall entail:

- Ensuring all installations are compliant with approved drawings.

- Measuring, before making any connections between cables, the free electrical status (En) relative to the soil of all structures, whether protected or not, and equipment 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:
 - Power supply voltage and DC output voltage (Uo) 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 current output.

8.3 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 DC sources, Contractor shall take preliminary readings (potentials and currents) to ensure that the system is fully operational and correctly adjusted. During this phase, the remote monitoring system, if any, shall be tested.

The readings shall be taken on the same reference point(s)/test point(s), in order to obtain consistent data when checking whether the protected structure(s) has been polarized or not.

Contractor shall record all results on data sheets, specific to each well casing and installation, drawn up for this purpose, for submission to Company.

8.3.1 Influence measurements

Whatever the type of cathodic protection system, contradictory influence measurements shall be given to Company after final adjustment to deal with any metal structure that is crossed or runs in parallel.

For potential variations greater than 50 mV, corrective actions must be decided between Company and the third parties involved.

9. Routine inspections

A further series of measurements shall be performed in the first three to four months of operation. The results shall demonstrate the effectiveness of each of the cathodic protection sub-systems.

Ideally CPET logs shall be conducted on representative well casings. The results of the CPET logs will be beneficial in verifying the level of protection being achieved on the casing and determining actual current requirements and any mutual interference effects between adjacent wells.

Any other CP potential measurements shall be carried out according to [EN 13509](#) or [NACE TM 0497](#).



10. Quality assurance

10.1 General

At the beginning of the design, a Quality Plan must be prepared by Contractor, detailing all actions related to cathodic protection calculations, definition of the systems to be installed procurement, quality control, and reception of equipment, and commissioning on site.

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

10.2 Technical file

The technical file submitted by Contractor at the end of the works shall include:

- The characteristics of the structures placed under cathodic protection
- The detailed calculations of the cathodic protection system
- The description of the sub-systems together with as-built location drawings, wiring diagrams and sketches
- The data sheets, test reports and certificates, datasheets of materials and equipment
- The results of sub-systems testing and commissioning
- The instructions for operation, inspection, and maintenance.