Engineering Standard

SAES-X-400 30 March 2005

Cathodic Protection of Buried Pipelines

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Saudi Aramco DeskTop Standards

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1 Scope

This standard prescribes the minimum mandatory requirements governing the design and installation of cathodic protection systems for onshore pressurized buried metallic pipelines outside of plant facilities. This standard does not address subsea pipelines or pipelines operated by Saudi Aramco Community Maintenance Departments

2 Conflicts and Deviations

2.1 Resolve any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes, and forms, in writing, with the Company or Buyer Representative through the Manager, Consulting Services Department (CSD) of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, CSD, Saudi Aramco, Dhahran.

3 References

Referenced standards and specifications shall be the latest edition, revision or addendum unless otherwise stated.

The Saudi Aramco Engineering Standards intranet web site contains the latest revisions of all standards and standard drawings.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedures

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirements*
SAEP-332	*Cathodic Protection Commissioning*
SAEP-333	*Cathodic Protection Monitoring*

Saudi Aramco Engineering Standards

SAES-B-064	*Onshore and Nearshore Pipeline Safety*
SAES-B-068	*Electrical Area Classification*
SAES-L-133	*Corrosion Protection Requirements for Pipelines/Piping*
SAES-P-104	*Wiring Methods and Materials*
SAES-P-107	*Overhead Distribution Systems*

SAES-P-111	*Grounding*
SAES-Q-001	*Criteria for Design and Construction of Concrete Structures*
SAES-X-600	*Cathodic Protection of Plant Facilities*

Saudi Aramco Materials System Specifications

02-SAMSS-008	*Insulating Joints/Spools for Cathodic Protection*
02-SAMSS-010	*Flanged Insulation Joints/Spools for Cathodic Protection*
17-SAMSS-004	*Conventional (Tap Adjustable) Rectifiers for Cathodic Protection*
17-SAMSS-005	*Cathodic Protection Phase Controlled Rectifiers*
17-SAMSS-006	*Galvanic Anodes for Cathodic Protection*
17-SAMSS-007	*Impressed Current Anodes for Cathodic Protection*
17-SAMSS-008	*Junction Boxes for Cathodic Protection*
17-SAMSS-012	*Photovoltaic Power Supply for Cathodic Protection*
17-SAMSS-017	*Impressed Current Cathodic Protection Cables*
17-SAMSS-018	*Remote Monitoring System (RMS) for Cathodic Protection Applications*

Saudi Aramco Standard Drawings

The following Saudi Aramco Standard Drawings outline specific methods of designing and installing cathodic protection systems:

AA-036069	*Galvanic Anodes at Thrust Anchors*
AD-036132	*Termination Detail Cable Identification*
AA-036145	*Cable Splice Junction Box*
AA-036157	*Galvanic Anode 3-Pin Test Station*
AB-036273	*Surface Marker Underground Electric Cable*
AB-036274	*5 Terminal Junction Box*
AB-036275	*12 Terminal Junction Box*
AA-036276	*Multi-Purpose Junction Box*
AA-036277	*5 Terminal Bond Box Details*
AA-036280	*Photovoltaic Power System*

AA-036346	*Surface Anode Bed Details - Horizontal and Vertical Anodes (Sheets 1 & 2)*
AA-036347	*20 Terminal Junction Box*
AA-036349	*3 Terminal Bond Box Details*
AA-036350	*2 Terminal Bond Box Details*
AB-036351	*Marker Plate Details*
AA-036352	*Galvanic Anodes for Road and Camel Pipeline Crossings (Sheets 1 & 2)*
AA-036378	*Rectifier Installation Details (Sheets 1 & 2)*
AB-036381	*Thermite Welding of Cables to Pipelines and Structures*
AA-036385	*Deep Anode Bed without Anode Support Pipe*
AA-036389	*Galvanic Anode Details*
AB-036540	*Mounting Support Details for Junction Boxes*
AC-036660	*Road Crossings for Pipelines*
AA-036674	*Bonding Details for Onshore Pipelines and Flowlines*
AA-036675	*Direct Buried Cable - Installation Details*
AB-036677	*An Overview - Architectural, Security & General Purpose Fencing*
AA-036678	*Security & General Purpose Fencing - Post & Fabric Details*
AD-036785	*Symbols - Cathodic Protection*
AA-036865	*Electrical Insulating/Isolating Assemblies*
AB-036907	*Test Stations for Buried Pipelines*

Saudi Aramco General Instructions

GI-0002.710	*Mechanical Completion and Performance Acceptance of Facilities*
GI-0428.001	*Cathodic Protection Responsibilities*

Saudi Aramco Inspection Procedure

17-SAIP-50	*Inspection Coverage of Cathodic Protection Deep Anode Beds*

3.2 Industry Codes and Standards

National Fire Protection Association

NFPA/NEC Handbook *National Fire Protection Association Publication of the National Electrical Code*

National Association of Corrosion Engineers

NACE RP0177 - 2000 *Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems*

4 Definitions

This standard uses the following terminology:

Cross-Country Pipeline: The pipeline and its appurtenances used to transport fluids across the country between isolated plant areas.

Design Agency: The firm responsible for designing the piping system. It could be the design Contractor, the Lump Sum Turn Key Contractor or in house design organization of Saudi Aramco.

Flowlines: Production pipelines connected to oil, gas or water wells for production, injection or well testing.

Off-Plot: Off-plot refers to any area outside of the **plot limits**. Off-plot can include plant areas such as roads, pipeways and open lots between plant units.

On-Plot: On-plot refers to any area inside the **plot limit**.

Perimeter-Fence: The fence which completely surrounds an area designated by Saudi Aramco for a distinct function (plant or camp).

Pipelines: When the term "pipeline" is used in this Standard it is meant to include both buried Cross-Country pipelines and Production pipelines"

Plant-Area: The designated area engaged in the production, processing, storage and transportation of crude oil, gas, refined products and their derivatives, typically inside a perimeter fence.

Plot Limit: The plot limit is a boundary, within the plant area, which surrounds a single plant or function. The plot limit may be physical such as a fence (not necessarily an SSD fence), a wall, the edge of a road or **pipe-way**, chains and posts or a boundary indicated on an approved plot plan.

Production Pipelines: Those pipelines engaged in transporting crude oil or gas from the producing wells to the designated facility for processing. These include flowlines, testlines, trunklines and transmission pipelines.

Testlines: Production pipelines that are used for testing an individual producing well without affecting the operation of the trunklines.

Transmission Pipelines: Production pipelines transporting product between GOSPs.

Trunklines: Production pipelines to which two or more flowlines are connected.

5 Design

5.1 Design Review and Approval

5.1.1 **IT IS MANDATORY** that the design package (construction drawings and the related cathodic protection design documents) be submitted to the proponent cathodic protection organization (as defined by GI-0428.001) **and** the Cathodic Protection & Coatings Unit of CSD for review and approval.

The design agency **shall not** issue drawings for construction that have not been approved in writing by the proponent cathodic protection organization **and** the Cathodic Protection & Coatings Unit of CSD.

Exception:

Design package approval is not required for CP designs based specifically on a CP standard drawing, e.g., galvanic anode installations per standard drawing AA-036352, for road and camel crossings on normally above grade pipelines with no dedicated CP systems.

5.1.2 The Supervisor of CSD/ME&CCD/Cathodic Protection and Coatings Unit and the Supervisor of the proponent cathodic protection organization shall indicate their review and approval of each Cathodic Protection drawing by signature.

Exception:

Design package approval, including approval of Index X construction drawings, can also be obtained using a cover form for a list of documents and drawings.

5.1.3 Review and approval of Remote Monitoring system design will be responsibility of IT/CIED/WEG.

5.1.4 The design package submitted for review shall contain at minimum:

a) The scope of work

b) Professionally drafted full size Index "X" CP drawings that:

- detail each CP item by description and stock number if applicable;
- detail the proposed location for each piece of CP equipment including but not limited to rectifiers, anodes, junction boxes, bond stations, test stations, and bonds to structures;
- detail and specifically identify all cathodic protection cables including all anode, structure, bond, and rectifier cables;

- clearly identify the specific and individual cable routing and termination points within the respective test stations, junction boxes, bond boxes, and rectifiers;
- detail all cathodic protection equipment using the cathodic protection symbols as shown on standard drawing AD-036785 "Symbols – Cathodic Protection";
- detail all existing CP installations in the area that could have an effect on the new CP system, and also provide information on spare current capacity of existing CP systems that will be utilized by the project.

c) All calculations and applicable field data required to verify design compliance with the Saudi Aramco Cathodic Protection Engineering Standards.

d) Remote Monitoring for Cross-Country pipelines shall be installed on Cross-Country pipeline rectifiers. It shall comply with 17-SAMSS-018 and shall be constructed to interface with existing Saudi Aramco Wireless Remote Monitoring System.

Commentary Notes:

1) Cathodic protection design considerations begin at the Design Basis Scoping paper (DBSP) stage and should be reasonably developed by the Project Proposal stage. The Project Proposal Design Package should include all design considerations that can be developed without acquiring actual field measurement data, including spare system capacity along the route of the proposed pipeline, proposed anode type(s) and sizing of the cathodic protection power source(s).

2) The Detailed Design Package submitted to CP&CU for review, should present a complete and comprehensive cathodic protection system design including all required field measurement data, calculations, a detailed description of the proposed cathodic protection equipment, and a set of detailed drawings that illustrate the proposed placement of all cathodic protection equipment and the associated protected structures.

3) As noted in GI-428.001, Section 2.8, PMT should request CSD/CP&CU to verify the qualifications of the engineer(s) designing the CP systems and installations. This should be done even in cases of design offices who have been previously involved in CP designs for Saudi Aramco, as changes in personnel could result in unqualified or inexperienced personnel to be assigned to these projects by the contractor design offices.

4) It is recommended that the CP design office hold a preliminary meeting jointly with CSD/CP&CU and the Proponent CP Group to outline their design approach for the Project Proposal or Detailed Design CP package, before starting work on the design package. This will help to eliminate a large number of the design review comments resulting from

inadequate field information or lack of in-depth existing CP system information, and speed up the review and approval process.

5.2 General

5.2.1 Cathodically protect all buried pipelines with impressed current cathodic protection (ICCP) systems. Buried sections of normally above-ground pipelines, such as camel crossings, road crossings, or electrically isolated buried sections of normally above-ground piping inside fenced areas and industrial area pipelines can be cathodically protected with galvanic anodes.

5.2.2 Design new cathodic protection systems to be compatible with existing systems. Before an impressed current CP system is designed for a new pipeline or section of a new pipeline, the protection levels (pipe to soil potentials) of close by pipelines that would be notably influenced by the same cathodic protection system(s) shall be measured, and the output levels and capacities of the existing CP systems shall be determined by the Design Agency. With the foregoing information, the Design Agency shall consider the use of surplus capacity of the existing CP systems for the protection of the new pipeline or pipeline segments. The use of surplus capacity of existing systems in lieu of the design and installation of a new CP system is preferred, however, it requires a dedicated letter showing written concurrence from the CP Proponent Organization, which shall be obtained prior to issuing the drawings for construction.

Commentary Note:

Proponent or CSD signatures on review packages do not satisfy or substitute for the requirement for written concurrence from the CP Proponent Organization for the use of surplus CP capacity from the CP Proponent Organizations existing CP facilities.

5.2.3 The cathodic protection of Production Pipelines is provided by the CP systems for the well casing(s) associated with the Production Pipeline. In unusual situations where the Production Pipeline extends more than 25 kilometers away from the nearest well casing CP system, it shall be treated as a Cross-Country Pipeline for the purposes of cathodic protection design requirements, and shall be covered within the scope of this Standard.

5.2.4 Install galvanic anodes according to Standard Drawing AA-036352 for the following structures:

- Buried valves and gas accumulators.
- Electrically isolated pipeline sleeves or casings.

- SSD fence crossings with bare copper grounding wires and/or copper or copper jacketed steel ground rods connected to them, at the inner and outer sides of the patrol road.
- Thrust bored road crossings.

  Exception:

  Galvanic anodes are not required for open cut paved or unpaved road crossings on normally buried pipelines with ICCP systems.
- Open cut road crossings and camel crossings on normally above-ground pipelines without dedicated ICCP systems.
- Pipeline thrust anchors located inside fenced areas or plant areas shall be provided supplemental protection using galvanic anodes, according to Standard Drawing AA-036069.

  Exception:

  1) Pipeline thrust anchors at well sites with ICCP systems do not require supplemental galvanic anodes.

  2) At gas well sites, if the flare and blow-down lines are stainless steel, coated and made continuous with the ICCP system, then galvanic anodes will not be needed at their thrust anchors.

  Commentary Note:

  If galvanic anodes are not practical, impressed current anodes can be used instead, specially, if other impressed current distributed anodes are installed within 150 meters of the structure to be protected.

5.2.5 Provide additional impressed current capacity at the ends of pipelines that are not isolated at plant terminations, at GOSP manifolds, at pump stations, at pipeline junctions, etc., to compensate for current loss to the underground metallic plant facilities. Special design considerations (e.g., additional CP current) are also required for buried pipelines at and inside the SSD fence limits for plants, industrial areas, pump stations, junctions, valve sites, GOSPs, etc. Coordinate these designs with, and obtain approval for them, from the Proponent and the Cathodic Protection & Coatings Unit of CSD.

5.2.6 Conduct induced AC simulation studies for new pipelines proposed to be installed in common right-of-ways with, and parallel to, high voltage overhead AC power lines, to determine if hazardous AC potentials would be induced on these lines. For new pipelines which are to be installed parallel to existing pipelines near AC power lines, measure the induced AC potential on the existing pipelines. If the calculated or measured AC potentials exceed those specified in SAES-B-064 as hazardous (higher than 12 volts AC, steady state), then design

and install induced AC mitigation devices to reduce the induced AC to a safe level.

5.2.7 Temporary C.P. Systems

5.2.7.1 Consider the use of CP current available through bonds to parallel and crossing pipelines (if applicable), before providing new galvanic anode temporary CP systems for the protection of new pipelines. Use of existing CP current for temporary protection requires the written concurrence of the proponent organization.

5.2.7.2 Provide temporary CP, within 30 days of burial as applicable, to each electrically dis-continuous sections of the pipeline, as these sections are constructed and buried. Potential survey data shall be submitted monthly to verify that the temporary system is providing adequate protection. Measure the current output for each galvanic anode station and submit it along with the monthly potential survey data while the temporary system is in operation.

5.2.7.3 Select low resistivity locations for installing galvanic anodes for temporary systems, to maximize the current output from these anodes and minimize the anode requirement. Install galvanic anodes on an "as required" basis, i.e., use the calculated numbers of anodes as a guide, and install anodes as required based on meeting the temporary CP protection criteria, to provide adequate temporary protection.

5.2.7.4 Install galvanic anodes for temporary cathodic protection using a 3-pin test station, using installation details given in standard drawing AA-036352. The number of anodes required per location shall be based on the actual requirement and not as shown on the standard drawing. If the temporary CP 3-pin test station location coincides with a KM marker/CP test station location, only install the 3-pin test station.

5.2.7.5 Disconnect galvanic anodes used for temporary CP systems when the permanent ICCP system is commissioned.

5.2.8 Remote Monitoring shall be installed on Cross-Country pipeline rectifiers. It shall comply with 17-SAMSS-018 and shall be constructed to interface with the existing Saudi Aramco Wireless Remote Monitoring System.

5.3 Design Life

5.3.1 The minimum design life of impressed current systems shall be 20 years.

5.3.2 The minimum design life of galvanic anode systems for electrically isolated short pipeline sections shall be 20 years.

5.3.3 The minimum design life of temporary CP systems shall be 2 years.

5.4 Current Density Criteria

5.4.1 The minimum current density requirements for "permanent" CP systems shall be as detailed in Table I.

Table I – Minimum Current Density Requirements

Pipeline Surface	Current Density (mA/m²)
Uncoated	20.00
Coated*	0.10

*** Note:** This is for coatings approved for use on new pipelines per SAES-H-002. Consult with CSD if any other type of coating is to be used.

5.4.2 The minimum current density requirement for temporary CP systems for coated pipelines shall be 0.005 mA/m².

5.5 Protection Criteria

5.5.1 Pipelines: The negative pipe-to-soil ON potential shall be a minimum of 1.2 volts and a maximum of 3.0 volts, with reference to a copper/copper sulfate electrode.

5.5.2 Pipeline Valves and associated buried piping: The negative pipe-to-soil ON potential shall be a minimum of 1.0 volt and a maximum of 3.0 volts, with reference to a copper/copper sulfate electrode.

5.5.3 Pipeline Junctions, Pump Stations, Compressor Stations, and other plant and industrial areas: The negative pipe-to-soil ON potential shall be a minimum of 1.0 volts and a maximum of 3.0 volts, with reference to a copper/copper sulfate electrode.

5.5.4 For all pipelines, cathodic protection must be achieved within 30 days of pipeline burial. If this schedule cannot be met, provide temporary cathodic protection as noted in 5.2.7 above.

5.5.5 For Temporary cathodic protection systems: The negative pipe-to-soil ON potential shall be a minimum of 1.0 volts and a maximum of 3.0 volts, with reference to a copper/copper sulfate electrode. Monthly potential survey data must be collected by PMT and submitted to the proponent, to demonstrate that the temporary system is providing effective cathodic protection. Remedial measures must be taken to restore effective CP to the minimum required potential criterion, within 30 days of any deficiency being noted. If required, additional anodes shall be installed as required to maintain the protection level on the pipeline until such time as the permanent ICCP system is commissioned.

5.6 Anodes

5.6.1 Impressed current anode materials for soil applications shall be high silicon cast iron according to materials specification 17-SAMSS-007. Magnesium galvanic anodes for soil applications shall comply with

materials specification 17-SAMSS-006. Design parameters are detailed in Table II, III and IV below.

Table II – Impressed Current Anode Design Parameters

Anode Material	Consumption Rate (kg/Ay)	Maximum Current Density (mA/cm²)
High Silicon Cast Iron	0.45	0.7

The impressed current anodes most commonly used by Saudi Aramco are listed in Table III below.

Table III – Impressed Current HSCI Anode Data

Type	Dimensions	Weight	Nominal Design Current	Maximum Commission Current
TA-4	95 mm x 2133 mm	38.6 kg	4.45 amps	7.0 amps
TA-5A	121 mm x 2133 mm	79.4 kg	5.67 amps	10.0 amps

Commentary Notes:

1) The consumption rate detailed in Table II considers the utilization factor. Shortening of the effective anode length due to an end cap on the anode shall be neglected in the theoretical calculation of anode current capacity.

2) The maximum commission currents detailed in Table III are based on manufacturer's ratings and shall not be used for design. This number shall only be used when determining commissioning acceptance.

3) Consult with the Cathodic Protection & Coatings Unit of CSD for the use of other types of impressed current anode materials such as mixed metal oxide or polymer anodes, for use in special applications.

Table IV – Galvanic Anode Design Parameters

Anode Material	Consumption Rate (kg/Ay)	Potential *(mV)* *($Cu/CuSO_4$)*
Magnesium	7.71	-1700

Commentary Note:

The consumption rate detailed in Table IV has been corrected for efficiency. A utilization factor of 0.85 may be included at the designer's discretion.

5.6.2 Anodes to be installed deeper than 15 meters shall be classified as "deep" anode beds, and as such require the drilling depth to be pre-approved in writing by the Groundwater Division of the Saudi Aramco Reservoir Characterization Department.

5.6.3 The minimum anode bed distance from the buried pipeline or adjacent underground structures shall be according to the rectifier rated output as follows:

Table V – Minimum Anode Bed Distances

Rectifier Rated Output	Minimum Anode Bed Distance From Buried Structure
35 Amps or less	35 Meters
50 Amps	75 Meters
100 Amps	150 Meters
150 Amps	225 Meters

For greater ampacities, these distances can be pro-rated as 75 meters distance for every 50 amperes of rectifier output.

Commentary Notes:

1) The distances specified above are provided to limit the structure theoretical potential to 3 volts, presuming an average soil resistivity of 3000 ohm-cm, and to minimize the interference effects on other independent cathodically protected structures. Shorter distances may be acceptable in lower resistivity soils if it can be shown based on calculations and/or operating data from existing systems in the vicinity of the proposed new system, that the shorter distance will not cause potentials above the 3 volts maximum, or cause interference effects on other independent cathodically protected structures. Resolve such situations on a case-by-case basis in consultation with CSD.

2) The "Rectifier Rated Output" values apply only to new CP systems being installed by projects. In the case of new pipelines being too close to existing anode beds, use the rectifier "nominal operating level" as the output value for the distances in Table IV. Resolve such situations on a case-by-case basis in consultation with CSD, and the proponent of the CP system.

3) Multiple deep anode beds can be treated as individual anode beds if the separation between the anode beds meets or exceeds the minimum distances detailed in Table V. Example: Two 50 amp deep anode beds placed 75 meters apart can be installed 75 meters away from a buried pipeline.

5.6.4 Separate adjacent anode beds powered from separate power sources by a minimum distance of 50 meters.

5.6.5 Circuit Resistance

5.6.5.1 The CP system "rated" circuit resistance for a rectifier shall be defined as the rectifier rated output voltage, divided by the rectifier rated output current.

5.6.5.2 The CP system "rated" circuit resistance for a photovoltaic cathodic protection power source shall be defined as the photovoltaic system rated output voltage divided by the design current (from Table 1) required to achieve adequate protection.

5.6.5.3 The CP system "design" circuit resistance shall be defined as the total effective resistance seen by the output terminals of the respective rectifier or photovoltaic output control center (OCC), and for calculation purposes shall include:

- Positive cable resistance from CP power source to anodes (including anode lead wire resistance between anode junction box and anodes)
- Anode bed resistance-to-earth
- Negative cable resistance from CP power source to structure
- Resistance of the pipeline to ground (0.01 ohms)
- Effective resistance caused by 2.0 volts back EMF between the anode and the pipeline.

5.6.5.4 Design new CP systems for a "design" circuit resistance less than or equal to 70% of the CP system "rated" circuit resistance.

5.6.5.5 The maximum acceptable CP system "operating" circuit resistance measured during commissioning (CP power source operating voltage divided by CP power source operating current) of a new CP system shall be less than or equal to 90% of the CP system "rated" circuit resistance, or must comply with 5.6.5.6.

5.6.5.6 The CP system "operating" circuit resistance measured during commissioning of a new CP system shall not be greater than 90% of the CP system "rated" circuit resistance unless the CP proponent organization provides written confirmation that:

a) The system can discharge the CP power source design current (Table I) with at least 3 fine tap setting increments remaining; and

b) each anode current, for the required minimum number of anodes, is at or below the maximum commission current rating (Table III); and

c) the required operating conditions indicate that the CP system will be able to provide the required cathodic protection for the lesser of 20 years or the predicted life of the structure.

Commentary Notes:

1) The intent of 5.6.5 is to provide a general upper limit to the installed anode bed resistance with some consideration for future increases in the anode bed resistance due to depletion of the anodes. It does not take into consideration site specific conditions such as the site actual AC input voltage, the rectifier actual maximum DC voltage, and the actual current required from the new CP system.

2) If an anode bed commissions at higher than 90% of the rated circuit resistance, but the CP system is able to discharge the required current with sufficient remaining voltage capacity to offset future resistance increases, supplementation of the anode bed may not be cost effective and deserves additional consideration. In such cases, the requirement for anode bed supplementation shall be at the discretion of the CP proponent organization.

3) Anode bed supplementation should always be considered if the CP system is unable to generate the rated current, or if at rated current, the current distribution from the anodes is imbalanced to the degree that any one of the anodes is discharging more than twice the current compared to the other anodes (up to a maximum of the Table III "anode commission current").

5.6.6 Distributed Anodes

5.6.6.1 Install distributed impressed current anodes where a remote anode bed will not provide satisfactory current distribution, or will not be practical. Distributed anodes are normally used for pipelines installed in congested areas, at SSD fence crossings where bare copper grounding wires or bare metallic ground rods are connected to the fence, at full-thrust anchors inside plant areas or fenced areas, at GOSP manifolds or flow line corridors, and where operational needs dictate.

5.6.6.2 Unless otherwise specified in this standard, the number, placement, current loading, and length of distributed anodes shall be determined by calculating the soil voltage gradients using the "earth potential rise" equations detailed in Appendix 1 of SAES-X-600.

5.6.7 Soil Resistivity Measurements

5.6.7.1 Surface Anode Beds: Conduct soil resistivity or soil conductivity measurements at 10 meter intervals over the full length of the proposed surface anode bed location. Ensure that the readings are taken for the planned installation depth of the anode bed. Mark the selected location of the surface anode bed with wooden stakes. Show the location on a detailed site sketch, and include this information on the CP design drawings. Also include information on the date and weather conditions during the survey, to allow for any considerations due to weather and seasonal variations affecting the soil resistivity.

Consult with the Cathodic Protection & Coatings Unit of CSD for design alternatives, if the soil resistivities over the length of the proposed anode bed vary by more than 100%.

5.6.7.2 Deep Anode Beds: Soil resistivity or soil conductivity measurements for deep anode beds are recommended but are not mandatory before the anode hole is drilled. Mark the selected location of the deep anode bed with a wooden stake. Show the location on a detailed site sketch, and include this information on the CP design drawings.

The Supervisor of the Cathodic Protection & Coatings Unit of CSD will determine the final bore hole depth and anode placement from drill stem and test anode data, as detailed in Section 6.2.3.3. The Saudi Aramco Project Engineer shall forward a copy of the drill stem and test anode data analysis and final design to the Supervisor of the Proponent CP group, for their information.

Commentary Note:

The intent of 5.6.7.2 is to eliminate the requirement for "electromagnetic" soil conductivity surveys in areas that have a low probability of being designed with surface anode beds.

5.6.7.3 Distributed Anode Beds: Conduct soil resistivity or soil conductivity measurements over a representative sample of the distributed anode installation locations. Ensure that the readings are taken for the planned installation depths of the anodes based on the finished grade levels at the site. Compare these measurements with previous data for the area, if available, to determine if the design results will be consistent with existing operating data. Show the location of the resistivities tests at the site in a detailed sketch, and include this information on the CP design drawings.

5.7 DC Power Sources

5.7.1 Use oil immersed rectifier units (Type OA enclosure) at all locations inside hydrocarbon plant areas, within 30 meters of a hydrocarbon plant perimeter fence (outside), or within 1 km of a coastline. Dry type air cooled units (Type AA enclosure) may be used at all other locations. Use rectifier units Type OA or Type AA, per 17-SAMSS-004 or 17-SAMSS-005.

5.7.2 See materials specification 17-SAMSS-012 for details of photovoltaic power supply system.

5.7.3 Install rectifiers and photovoltaic systems in accessible locations, with an all-weather marl road and as far away from sand dunes as possible. Perform sand stabilization, where necessary, to prevent sand dune encroachment.

5.7.4 Do not use DC power supplies with a rated output voltage greater than 100 volts. The sizing of the rectifier shall be optimized and based on the overall circuit resistance. Rectifier sizes other than those listed in SAMSS category 17 can be used, but must be approved by the Supervisor of the Cathodic Protection and Coatings Unit of CSD.

5.7.5 Do not install DC power supplies in hazardous locations.

5.8 DC Cables

5.8.1 NEC Table 310-16 (90°C rating column) shall be used to determine the minimum size (allowable ampacity) for HMWPE/HDPE cables. The cable size shall be corrected for an ambient temperature of 40°C.

5.8.2 NEC Table 8, Chapter 9, shall be used to determine resistance properties. The resistance of the cables shall be considered in the anode bed design to ensure compliance with Section 5.6.5.

Commentary Note:

See materials specification 17-SAMSS-017 for details of approved DC cathodic protection cables.

5.9 Monitoring Facilities

5.9.1 Provide a test station for measuring pipe-to-soil potential at each kilometer marker of the buried sections of pipelines, negative connection, thrust anchor, insulated cased crossing, thrust-bored road crossing, paved road crossing and other locations as required by operational needs and according to Standard Drawing AB-036907.

5.9.2 Install soil access test stations at 20 meter intervals in paved areas, directly over the pipeline. See Standard Drawing AB-036907 for soil access test station details.

5.9.3 At pipeline transitions through asphalt or concrete, provide 30 cm of unpaved soil around the transition, for potential monitoring soil access and CP current flow to the pipeline in the transition area.

5.9.4 For distributed anode systems, install soil access test stations over the pipeline midway between each pair of anodes, at a location over the pipeline closest to the anode, and one at the beginning and one at the end of each pipeline segment.

5.10 Bonding

5.10.1 Provide electrical continuity bonding for buried bolted pipeline fittings (flanges, flanged valves, etc.).

5.10.2 Provide electrical continuity bonding between pipelines to prevent interference. All pipeline bond terminations shall be made above-grade, in an approved electrical enclosure.

5.10.3 Limit the minimum bond conductor size to 16 mm² (#6 AWG).

5.10.4 Bond all buried parallel pipelines, separated by a distance of 50 meters or less, through a bond box at the beginning and at the end of the parallel segment. Also bond parallel pipelines at all CP power supply locations and at 10 km intervals.

Commentary Note:

See Section 5.9.1, 6.4.6, 6.4.9 and 6.6.6 for other negative cable connection and test station requirements at CP power supply locations. If the conditions of 5.10.4 overlap, eliminate bonds less than 100m apart.

5.10.5 Bonding shall be provided at all locations where buried in-service, mothballed, or foreign metallic pipelines cross. Foreign pipelines shall be bonded to Saudi Aramco pipelines through a variable resistor installed inside a bond box.

5.10.6 Bond normally above-ground parallel pipelines, separated by a distance of 50 meters or less, or a combination of above-ground and buried pipelines, at common camel or road crossings, on one side of the crossing according to Standard Drawing AA-036674.

5.10.7 Do not bond any pipeline to an abandoned pipeline.

5.10.8 Bonding is only required between a crossing pipeline and the outer pipelines in multiple pipeline corridor. The pipeline corridor must comply with section 5.10.4.

5.10.9 When bonding a new parallel pipeline to existing pipelines in a multiple parallel pipeline corridor, bond the new pipeline only to the nearest existing pipeline. The pipeline corridor must comply with section 5.10.4.

5.10.10 Electrically isolated flanged piping sections (spool pieces), installed inline for use with instrumentation or other applications, shall be bonded around using a metal bond strap, installed by removing and replacing one nut and associated insulating washer and sleeve from each flange.

5.10.11 All bonding shall be according to Standard Drawing AA-036674.

5.10.12 See materials specification 17-SAMSS-008 for details of bonding and junction boxes.

5.11 Electrical Isolation

5.11.1 Electrical isolation of pipelines is required at, but not limited to, the following locations:

a) Connections to **unprotected** metallic structures, such as at scraper traps and valve stations.

b) Metallic supports on above ground bypasses and crossovers

c) Motor-operated valves not in seawater service

d) Onshore-offshore transitions

e) Off-plot at plants, except at GOSPs, WIPs, junctions and pump stations

f) Off-plot at non-Saudi Aramco plants

g) All steel pipeline anchors and steel pipeline supports

h) At product pipeline to bulk plant transitions

Commentary Note:

Additional cathodic protection may be used instead of Electrical Isolation for b, c, g & h. The CP design shall be approved by the Cathodic Protection & Coatings Unit of CSD.

5.11.2 Do not install insulating/isolating devices in any buried or submerged portions of pipelines.

5.11.3 Do not install insulating/isolating devices in areas classified as hazardous locations.

5.11.4 Provide bond boxes for all isolating devices. Bonding to piping on the non-Saudi Aramco plant side of an isolating device shall be through a variable resistor installed inside the bond box.

Exception:

Bond boxes are not required for isolation devices installed for short sections of buried piping protected by galvanic anodes (as specified in 5.2.1 above).

5.11.5 Bond wires from adjacent isolating devices at plant terminations may be terminated in a common bond box.

5.11.6 Consider installing pipeline isolating devices at the termination points of above-grade piping runs when electrical insulation of large pipeline supports becomes impractical and uneconomical. This also applies to both ends of short buried sections of normally above grade pipelines in plants and industrial areas, which are not protected by impressed current systems.

5.11.7 See materials specification 02-SAMSS-008 and 02-SAMSS-010, and standard drawing AA-036865 for details of pipeline isolation devices.

5.12 Flow Lines, Trunk Lines and Test Lines

Buried portions of all flowlines, trunklines, and testlines shall comply with the protection criteria detailed in Section 5.5.

5.12.1 Aboveground Flow Lines, Trunk Lines and Test Lines

5.12.1.1 For normally above ground lines without dedicated CP systems, install two magnesium anodes at the center of the crossing, one on each side of a pipeline, at all bermed-over camel crossings on normally above ground lines, and open-cut road crossings (paved or marl), according to Standard Drawing AA-036352, with a galvanic anode 3-pin test station installed on the down-station or GOSP side of the crossing.

5.12.1.2 Install two magnesium anodes at thrust-bored crossings or coated casings (sleeves), on each side of the crossing, according to Standard Drawing AA-036352. Provide a galvanic anode 3-pin test station for each installation.

5.12.2 Buried Flow Lines, Trunk Lines and Test Lines

5.12.2.1 Install four magnesium anodes at full-thrust anchors located inside plant areas or fenced areas, with a galvanic anode 3-pin test station, installed according to Standard Drawing AA-036069.

Commentary Note:

If galvanic anodes are not practical, impressed current anodes can be used for the above, specially if other impressed current distributed anodes are installed within 50 meters of a thrust anchor. In this case, two impressed current anodes shall be installed within 15 meters of the anchor, and placed on opposite sides of the anchor.

5.12.2.2 Install two magnesium anodes at thrust-bored crossings or coated casings (sleeves), on each side of the crossing,

according to Standard Drawing AA-036352. Provide a galvanic anode 3-pin test station for each installation.

5.12.3 Flow Lines, Trunk Lines, and Test Lines, at GOSPs

5.12.3.1 Install two magnesium anodes for each inner and outer patrol road at SSD fence crossings, where bare copper grounding wires or copper or copper jacketed steel ground rods are connected to the fence. Install anodes according to Standard Drawing AA-036352, with the anodes located on each side of the pipeline and as close to the center of the patrol road as possible. Locate the galvanic anode 3-pin test station on the opposite side of the patrol road from the SSD fence.

Commentary Note:

If galvanic anodes are not practical, impressed current anodes can be used for the above, specially, if other impressed current distributed anodes are installed within 50 meters of a fence.

5.12.3.2 Tie-in the flow lines, trunk lines and test lines to the GOSP CP system, with the written permission of CP Operations. Cathodic Protection & Coatings Unit of CSD shall approve the design. Additional distributed impressed current anodes and/or an additional CP power source may be required. Separate negative leads are required for each line.

5.12.3.3 Flow lines, trunk lines, and test lines, inside GOSPs must comply with Sections 5.6.3, 5.12.1, and 5.12.2 of this document.

5.12.3.4 Install a one-pin test station for buried pipelines, outside the GOSP SSD fence on the opposite side of the patrol road. This one-pin test station is not required if a 3-pin test station is installed as specified in 5.12.3.1 above.

5.12.3.5 Install continuity and/or cross-bonding for all flow lines, trunk lines, and test lines, according to Standard Drawing AA-036674 and Section 5.10 of this document.

6 Installation

6.1 Galvanic Anodes

Install galvanic anodes in accordance Standard Drawing AA-036352. Refer to 6.4.5 below, for inspection and repair of galvanic anode cable leads. Instructions given in 6.2.1.2 below are for impressed current anodes, and do not apply to galvanic anode cable leads.

6.2 Impressed Current Anodes

6.2.1 General

6.2.1.1 Install all anodes in sequential order. Durably tag cables, according to Standard Drawing AD-036132, to indicate the anode number at the termination point inside the anode lead junction box.

6.2.1.2 Inspect impressed current anode cable leads for below grade usage for insulation damage just before installation, and backfill anode cable trench immediately following this inspection. Conduct the inspection with a certified and calibrated pulse type holiday detector set at 18,000 volts DC. Saudi Aramco or its designated agent shall witness the test. Do not use anodes with cables that fail the dielectric test. Also conduct a visual and touch inspection of the anode cable insulation immediately adjacent to the head of the anode. Anode leads with noticeable "necking", or an obvious reduction in diameter of the insulation, shall not be used.

Commentary Note:

ANODES SHOULD NEVER BE ROLLED, PARTICULARLY WHILE THE ANODE CABLE IS STILL ON THE SPOOL. Rolling an anode while the anode lead wire is on the spool can cause "necking" of the anode cable insulation at the head of the anode where the anode cable exits the epoxy plug. This installation-induced defect results in premature anode failure and is not detectable with the electronic holiday detector.

6.2.1.3 Do not use repaired impressed current anode cable leads, anodes, or anodes with repaired anode-to-cable connections.

6.2.1.4 Mark the exact location of the anode bed with a wooden stake(s) and verify the proper burial depth, before construction starts. The designated Saudi Aramco design or construction agency will mark and verify location and depth, based on information given in the approved construction drawings.

6.2.2 Surface Anode Beds

6.2.2.1 Install surface anode beds according to Standard Drawing AA-036346, at the location and depth determined from soil resistivity measurements and specified on the project site layout drawing.

6.2.2.2 Connect the number one anode to the farthest anode terminal located on the right hand side of the anode lead junction box, when facing the front of the box.

6.2.3 Deep Anode Beds

6.2.3.1 Install deep anodes according to Standard Drawing AA-036385, Deep Anode Bed without Anode Support Pipe. Refer to 17-SAIP-50 "Inspection Coverage of Cathodic Protection Deep anode Beds" for inspection guidelines to be followed during installation.

6.2.3.2 The Groundwater Division of the Saudi Aramco Reservoir Characterization Department shall pre-approve all deep anode bed installations. This approval will be obtained by the responsible design agency office who will forward a copy to the construction agency.

6.2.3.3 Take drill stem resistance and test anode resistance measurements during drilling of the anode hole, in accordance with the requirements detailed in Standard Drawing AA-036385. Use a certified and calibrated 4-pin resistance meter to take these measurements. Submit this data (along with the CSD conceptual design information, if any, and Groundwater Division approval) for review and analysis to the Supervisor of the Cathodic Protection & Coatings Unit of CSD, who will determine the final acceptable bore hole depth, and anode placement for optimal current distribution and anode bed resistance. Also provide a copy of the field test data and analysis to the CP engineering group of the proponent organization, for their review and approval.

6.2.3.4 Install the number one anode at the bottom of the bore hole. Connect the number one anode to the farthest anode terminal located on the right hand side of the anode lead junction box, when facing the front of the box.

6.2.4 Distributed Anodes

Install each distributed anode with an individual anode lead wire to an anode junction box, and with an individual shunt for each anode.

6.3 DC Power Source

6.3.1 Rectifiers and photovoltaic systems shall be installed in accessible locations as far away from sand dunes as practical. The construction contractor shall provide sand stabilization where conditions in the area indicate a high probability for sand dune encroachment, and in areas of

probable drifting sand, oil immersed rectifiers shall be mounted a minimum of 300 mm above ground to minimize sand accumulation against the rectifier.

6.3.2 Rectifiers

6.3.2.1 Install rectifiers according to Standard Drawing AA-036378 (Sheets 1 & 2). The installation shall comply with the electrical requirements detailed in SAES-P-104, SAES-P-107 and SAES-P-111.

6.3.2.2 Provide AC power input to the rectifier through a fused disconnect switch or circuit breaker with an externally operable handle mechanism. Enclose the device in a NEMA 3, 4 or 4X enclosure, with the exception that NEMA 4X enclosures shall be used for all locations within one kilometer from the shoreline of the Arabian Gulf; all of the Ras Tanura Refinery and Terminal; and within three kilometers from the shoreline of the Red Sea. Refer to SAES-P-104 for enclosure NEMA rating requirements. Mount the device in an accessible location approximately 1.8 meters above grade and within 3 meters of the rectifier. Rate the circuit breaker to 125% of the rectifier input current at rectifier rated load, or for the nearest commercially available 125% rating of the rectifier rated input current.

6.3.3 Photovoltaic Power Supplies

6.3.3.1 Install the photovoltaic power supply according to Saudi Aramco Standard Drawing AA-036280.

6.3.3.2 In installations where more than one module is used, place up to four modules side by side, with all panels facing due south. Use additional rows for more than 4 modules. Physically configure modules such that shadows from any module do not affect any other module.

6.4 DC Cables

6.4.1 Install all buried DC cables according to Standard Drawing AA-036675.

6.4.2 Identify all buried DC cables (anode leads, bond, positive, and negative cables) by cable route markers according to Standard Drawing AB-036351.

6.4.3 Inspect all positive cables and lead wires for burial for insulation damage immediately prior to installation. Inspect with a pulse type

holiday detector set at 18,000 volts DC. Check the holiday detector according to the manufacturer's instructions and make sure that it has a valid calibration sticker within six month before operation. Repair of the insulation for buried positive cable by any method is prohibited. Above-grade repair connections for anode bed positive cables in splice boxes are acceptable. See Standard Drawing AA-036145 for cable splice box details.

6.4.4 Limit buried main positive cable runs (e.g., between rectifier and anode bed junction box) to 150 meters. Make splices at 150 meter intervals in above-grade splice boxes. For sections of cable between 150 meters and 300 meters in length, locate the splice box approximately at the midpoint. See Standard Drawing AA-036145 for cable splice box details.

6.4.5 Visually check negative cables and bond cables for buried service for obvious insulation defects. Repair cables with visible insulation damage with 3 half-lap layers of plastic vinyl tape over 3 half-lap layers of rubber tape.

6.4.6 Use thermite welds for all negative drain cable and bond connections to steel pipes and structures, according to Standard Drawing AB-036381. Terminate the cable from the pipeline(s) in an individual above-grade splice or junction box located as close to the connection point as possible, but away from the pipeline berm. A multipurpose junction box located in the corridor may be utilized for multiple pipelines. An individual test lead with marker post is still required at the negative connection.

6.4.7 Encase above-grade cables in conduit, or install in covered cable trays. Alternatively, armored cable can be used.

6.4.8 Install individual shunts for each multiple positive and negative cable circuit, in all junction or bond boxes.

6.4.9 Install individual negative connections and individual negative cables for all buried pipelines.

6.4.10 At multiple parallel pipeline locations, use a bond box instead of a junction box to connect the individual pipeline negative cables to the CP power source. This will satisfy the requirement of Section 5.10.4, and will avoid installation of a junction box as well as a bond box at such locations. Do not connect test leads inside this bond box. Install an individual test lead with marker post at the negative connection, as required per section 5.9.1.

6.5 Grounding Conductors

General: All grounding conductors for new construction in areas where CP is provided for buried piping shall be jacketed and installed with non-copper grounding, as specified in SAES-P-111. For locations where existing bare copper grounding is installed, follow the guidelines given below.

6.5.1 Insulate buried bare copper conductors crossing a pipeline for a minimum of 6 meters on each side of the pipeline crossing. The insulation may be PVC conduit, coated cable or other approved method.

6.5.2 Do not use bare copper conductors when running parallel within 3 meters of a buried pipeline or piping.

6.5.3 Do not provide dedicated grounding to junction, splice or bond boxes.

6.6 Test Stations, Bond Boxes, and Junction Boxes

6.6.1 Complete the installation of bond box wiring to the new pipeline, including wire labeling for all bonding station installations, within 7 days from the date the pipeline is covered with backfill, and extend the connected wiring above grade. Connect the bond wires from the new pipeline to the crossing or parallel pipelines using temporary connections, as soon as the wiring is installed on the new pipeline. The bond station shall be installed and connected within 7 days from the date the berm over the new pipeline is completed.

6.6.2 Complete the installation of test lead wiring to the new pipeline, including wire labeling for all test station installations, within 7 days from the date the pipeline is covered with backfill. Extend the test leads above grade, to facilitate CP potential measurements prior to the installation of the test stations. The test station shall be installed and connected within 7 days from the date the berm over the new pipeline is completed.

6.6.3 Install test stations, bonding stations, and anode junction boxes in accordance with the standard drawings listed in Section 3 of this standard, and at the locations shown on the construction drawings.

Exception:

In areas where theft and vandalism may be problematic, below grade splices may be substituted for above grade junction boxes with written concurrence from the cathodic protection proponent organization and from the Supervisor of the Cathodic Protection and Coating Unit of Consulting Services Dept. In such cases, the splice procedure must be pre-approved by the Proponent and CSD, and installation must be witnessed as dictated by the Proponent and CSD.

6.6.4 Identify all cables inside test stations, bonding stations and junction boxes with durable tags according to Standard Drawing AD-036132.

Label the cable and the terminals (in accordance with the construction drawings) to indicate the structures to which they are connected.

6.6.5 Provide all bond and junction boxes with an outside and an inside nameplate indicating the identification number of the rectifier unit or structure to which they are connected, or both. For positive and negative junction boxes, this also includes a location schematic engraved on the nameplate, when required by the proponent.

6.6.6 Install shunts for multiple positive or negative cables in each junction box for each circuit.

6.7 Concrete Foundations and Footings

Construct concrete foundations, footings and supports in accordance with Saudi Aramco Engineering Standard SAES-Q-001.

6.8 Fencing and Guardrails

6.8.1 Protect transformers, rectifiers, and photovoltaic power supplies located outside existing plant security fences from damage, with a type IV fence. Details of type IV fencing are shown on Standard Drawings AB-036677 and AA-036678.

6.8.2 Do not locate rectifiers inside an electrical substation or any other fenced area that is not normally accessible to CP operating and maintenance personnel, unless the fencing around the area is modified with a separate entry to allow access to the rectifier.

6.8.3 Include guardrail facilities for anode bed junction boxes and watering pipes at sites where vehicular traffic or other conditions in the area indicate a high probability of damage.

7 Commissioning and Inspection

7.1 Commissioning

Conduct all pre-commissioning and commissioning in accordance with GI-0002.710 and SAEP-332.

7.2 Inspection

Notify Project Inspection and/or the Proponent Operations Inspection before the start of construction, so that full inspection coverage can be provided during construction, and especially during anode installations. Provide test data sheets to the inspection agency for review at least three days, but not more than one week prior to the start of construction.

8 Records

Update all Construction drawings for any field modifications to the original design to show the "as built" cathodic protection system. Show the type and location of all cathodic protection equipment on the as-built drawings. Submit copies of these updated drawings to the cathodic protection proponent department and the Consulting Services Department within sixty (60) days of project completion. Complete reported corrections (if any) within thirty days.

Revision Summary

30 March 2005 Major revision.