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# Petroleum, petrochemical and natural gas industries — Prevention of corrosion on pipeline systems influenced by stray currents

*Industries du pétrole, de la pétrochimie et du gaz naturel — Prévention de la corrosion sur les systèmes de conduites soumis à l'influence de courants vagabonds*

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# Foreword

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This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 2, *Pipeline transportation systems*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 219, *Cathodic protection*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

This document provides guidance for the prevention of external corrosion when a pipeline is influenced by electrical interference. Electrical interference can be from stray currents (defined in ISO 8044) and from naturally occurring interference caused by geomagnetic or tidal activity.

International Standards on cathodic protection (e.g. ISO 15589-1 and ISO 15589-2) refer to a structure-to- electrolyte potential value that is considered to indicate that cathodic protection is effective. When the potential is influenced by stray currents, however, it is not always possible to obtain a meaningful structure-to-electrolyte potential and other methods of assessment are needed. These other methods can include mathematical analysis of the potentials and/or direct assessment of the corrosion rate using electrical resistance probes.

An affected structure carrying stray currents, e.g. a pipeline or cable can itself affect other nearby structures.

This document is not intended to inhibit the use of alternative equipment or engineering solutions for individual applications. Where an alternative is offered, it is intended that any variations from this document be identified and documented.

# Petroleum, petrochemical and natural gas industries — Prevention of corrosion on pipeline systems influenced by stray currents

## 1 Scope

This document establishes the general principles for the evaluation and minimization of the effects of stray current corrosion on external surfaces of buried or immersed pipeline systems caused by AC and DC electrical interference.

Other stray current effects such as overheating, and interference with welding operations are not covered in this document.

A brief description of AC effects, general principles and some guidelines, are provided.

NOTE 1 See ISO 18086 for the effects of alternating current on buried or immersed pipelines.

Systems that can also be affected by stray currents include buried or immersed metal structures such as the following:

a) pipeline systems;

b) metal sheathed cables;

c) tanks and vessels;

d) earthing systems;

e) steel reinforcement in concrete;

f) sheet steel piling.

This document gives guidelines for

- the design of cathodic protection systems that might produce stray currents,
- the design of pipeline systems, or elements of pipeline systems, which are buried or immersed, and which can be subject to stray current corrosion, and
- the selection of appropriate protection or mitigation measures.

Internal corrosion risks from stray currents are not dealt with in detail in this document but principles and measures described here can be applicable for minimizing the interference effects.

NOTE 2 The impact of electromagnetic interference on above-ground appurtenances of pipeline systems is covered in EN 50443, EN 61140, IEC 60364-4-41, IEC 60479-1, IEC 60364-5-52, IEC/TS 61201 and IEC/TR 60479-5.

This document can also be used for pipeline systems outside of the petrochemical and natural gas industries and other buried or immersed structures.

NOTE 3 EN 50162 provides guidance for railway related structures.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62128-2:2013, *Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 2: Provisions against the effects of stray currents caused by d.c. traction systems*

ISO 15589-1, *Petroleum, petrochemical and natural gas industries — Cathodic protection of pipeline systems — Part 1: On-land pipelines*

ISO 8044, *Corrosion of metals and alloys — Vocabulary*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15589-1, IEC 62128-2:2013, ISO 8044 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

### 3.1

**coating**

electrically insulating covering bonded to a metal surface for protection against corrosion by preventing contact between the electrolyte and the metal surface

### 3.2

**remote earth**

theoretical concept that refers to a ground electrode of zero impedance placed an infinite distance away from the ground under test

Note 1 to entry: In practice, remote earth is approached when the mutual resistance between the ground under test and the test electrode becomes negligible. Remote earth is normally considered to be at zero potential.

[SOURCE: IEEE Std 81-1983[1]]

### 3.3

**conductive coupling**

transfer of energy occurring when a part of the current belonging to the interfering system returns to the system earth via the interfered system

Note 1 to entry: Also, when the voltage to the reference earth of the ground in the vicinity of the influenced object rises because of a default in the interfering system, and the results of which are conductive voltages and currents.

### 3.4

**drainage**

**electrical drainage**

transfer of stray current from an affected structure to the current source by means of a deliberate bond

Note 1 to entry: For drainage devices see *direct drainage bond* (3.5), *unidirectional drainage bond* (3.7) and *forced drainage bond* (3.6).

### 3.5

**direct drainage bond**

device that provides *electrical drainage* (3.4) by means of a bi-directional, metallic bond between an affected structure and the stray current source

Note 1 to entry: The bond can include a series resistor to reduce the current.

### 3.6
**forced drainage bond**

device that provides *electrical drainage* (3.4) by means of a bond between an affected structure and the stray current source

Note 1 to entry: The bond includes a separate source of DC power to augment the transfer of current.

### 3.7
**unidirectional drainage bond**

device that provides *electrical drainage* (3.4) by means of a unidirectional bond between the affected structure and the stray current source

Note 1 to entry: The bond includes a device such as a diode to ensure that current can only flow in one direction.

### 3.8
**telluric interference**

voltages generated by geomagnetic field variations that cause variations in the observed pipe-to-soil potentials

### 3.9
**electrical resistance probe**

**ER probe**

metal loss measured by comparison of the calibrated resistance value of a piece of metal with known physical characteristics

### 3.10
**sampling rate**

measuring interval set by the operator

### 3.11
**alternating current interference**

**AC interference**

electrical disturbance generated by AC systems that affects buried or immersed pipelines by conduction and/or induction

Note 1 to entry: Powerlines, railway traction systems.

### 3.12
**direct current interference**

**DC interference**

disturbance, generated by DC systems, that affects buried or immersed metallic structures primarily by conduction

## 4 Abbreviations and symbols

### 4.1 Abbreviations

| | |
|---|---|
| AC | Alternating current |
| CP | Cathodic protection |
| DC | Direct current |
| emf | Electromotive force |
| GIC | Geomagnetically induced currents |
| HVAC | High voltage alternating current |

| | |
|---|---|
| HVDC | High Voltage Direct Current |
| IR | Product of the current and resistance (I and R) that indicates the voltage drop error in a potential measurement |
| PV | Photovoltaic |
| r.m.s. | Root mean square |

## 4.2 Symbols

| | |
|---|---|
| $a^{-1}$ | Per annum |
| $E$ | Structure/soil potential for non cathodically protected structures |
| $E_a$ | Anodic potential |
| $E_c$ | Cathodic potential |
| $\Delta E$ | Potential difference due to operation / non-operation of the interfering source |
| $\Delta E_a$ | Anodic potential shift (IR drop included) |
| $\Delta E_{a,avg}$ | Average anodic potential shift |
| $\Delta E_{a,\text{IR free}}$ | Anodic potential shift (IR drop excluded) |
| $\Delta E_c$ | Cathodic potential shift |
| $\Delta E_{c,avg}$ | Average cathodic potential shift |
| $E_{cor}$ | structure potential of a metal in a given corrosion system (ISO 8044) |
| $E_{\text{IR-free}}$ | Structure potential without measurement error due to current flowing in the circuit |
| $v_{cor}$ | Corrosion rate |
| $E_{on}$ | ON potential |
| $E_{on,avg}$ | Average ON potential |
| $E_p$ | Protection potential according to ISO 15589-1 |
| $E_{ref}$ | On potential required to achieve effective cathodic protection |
| $J_a$ | Anodic current density |
| $J_c$ | Cathodic current density |
| $J_{ref}$ | Reference value for current density (analogous to $I_{ref}$) |
| $\rho$ | Soil resistivity (Ω.m) |
| $Q_a$ | Anodic charge during the period of anodic interference |
| $Q_c$ | Cathodic charge during the period of cathodic interference |
| $R_{iso}$ | Isolation resistance, usually of a cable insulation |
| $t$ | Time |

| | |
|---|---|
| $T_a$ | Interval when the structure is anodic with respect to the selected value of $E_{\mathrm{ref}}$ or $J_{\mathrm{ref}}$ |
| $T_{\mathrm{a,max}}$ | Maximum duration of the anodic period |
| $T_{\mathrm{c}}$ | Interval when the structure is cathodic with respect to the selected value of $E_{\mathrm{ref}}$ or $J_{\mathrm{ref}}$ |

## 5 Information exchange and co-operation

Common sources of interference that can cause stray current corrosion are given in Clause 6. During the design stage of buried or immersed metallic pipeline systems, the possibility of both causing and suffering from stray current interference shall be taken into consideration and documented. The pipeline system should achieve the protection criteria identified in Clause 8. Construction work, major changes on existing structures, regenerative braking, etc. can require a detailed consideration of the interference situation.

Electrical interference problems on buried or immersed metallic pipeline systems shall be considered, and documented, with the following points in mind:

- The operator of the pipeline system can protect a structure against corrosion with the method that the operator considers to be the most suitable. However, levels of electrical interference on neighbouring structures shall be maintained within the defined limits given in Clause 8
- Stray currents, especially from DC traction systems, are directly related to the design of the traction return circuits. This means that it is possible to limit the stray current by traction circuit design, but not to eliminate it.
- Where other structures that might be affected are present, the requirement to maintain interference within the defined limits applies to all affected structures.
- Utility-scale photovoltaic (PV) installations can develop a steady state DC interference to adjacent buried pipelines. It is expected that the operator of the PV installation will maintain constant monitoring of the $R_{\mathrm{ISO}}$ value to verify the isolation resistance between the PV panels and the earth. The pipeline operator should be informed of any changes in the $R_{\mathrm{ISO}}$ values outside the threshold value.
- The operating characteristics of HVDC systems can change under fault and maintenance conditions. These changes can affect the corrosion risk to buried pipelines and such changes should be communicated in a timely manner to the pipeline operator.

These goals are best achieved by agreement, co-operation and information exchange between the parties involved. Information exchange and co-operation are important and shall be carried out both at the design stage and during operation of the systems. In this way possible effects, suitable precautions and remedies can be assessed.

The following information is required to make a sound engineering judgement:

- details of buried metallic structures;
- cathodic protection installations or significant modifications to existing installations;
- DC traction system installations or significant modifications to existing installations;
- HVDC transmission line installation or modification to existing installations or modes of operation;
- details of any sources of DC installations that can cause interferences to buried pipelines;
- utility scale photovoltaic systems.

Agreement and co-operation is more effectively achieved and maintained by periodic meetings between interested parties, committees or other associations who can establish information exchange procedures and protocols.

# 6 Common sources of interference that can affect corrosion

## 6.1 General

DC systems that can cause currents to flow in the earth or any other electrolyte, whether intentional or unintentional, include the following:

a) traction systems;

b) overhead lines for vehicles;

c) trolley bus systems;

d) power systems;

e) equipment at industrial sites, e.g. welding;

f) communication systems;

g) instrumentation systems;

h) cathodic protection systems;

i) high voltage transmission systems. (See Annex E);

j) track circuit signalling systems. (For stray currents from traction systems, IEC 62128-2 gives requirements for minimizing their production and for the effects within the railway system);

k) photovoltaic power systems;

l) offshore wind farm power systems;

m) geomagnetic interference (telluric currents);

n) tidal fluctuations.

AC systems that can induce voltages into buried structures include

- three phase power transmission overhead cables,
- buried three phase power cables, and
- AC operated railways.

## 6.2 Direct current

### 6.2.1 General

Sources of DC that can affect the structure-to-electrolyte potentials on pipelines can either originate from industrial or natural sources.

### 6.2.2 Traction systems

There are various configurations of DC traction systems that are in common use. They generally differ in respect of the way that the current is returned to the substation(s). Whichever system configuration is used there will be some current that returns via the earth. IEC 62128-2 gives guidance on permissible limits.

### 6.2.3 Industrial systems

#### 6.2.3.1 General

Industrial systems that use, or generate, DC should be provided with earthing systems that neither rely on long earth return paths nor deliberately utilize third-party structures for earthing purposes.

#### 6.2.3.2 Welding

Welding return circuits should be configured to ensure that the return paths are as short as possible and do not exacerbate the risk of currents returning via third-party structures.

#### 6.2.3.3 Photovoltaic interference on buried pipelines

Leakage currents in photovoltaic systems originate from a fault or from the systematic and inevitable flow of DC where there is cable insulation damage to PV modules and other array components. Under certain conditions, the DC leakage currents, if left unattended, or not detected at all, can cause accelerated stray current corrosion on metallic underground infrastructure, such as pipelines, buried near large, utility-scale PV systems.

## 6.3 Alternating current

### 6.3.1 General

AC powered systems can cause interference on pipelines due to inductive, conductive and capacitive coupling mechanisms, which are described in Reference [3].

It is possible that the voltage resulting from interference on the pipe can exceed acceptable levels of touch-potential and/or current densities that will lead to corrosion damage of exposed steel surfaces.

The potentials and current densities that are used to determine the risk of corrosion from AC interference are detailed in Reference [3].

Annex F provides additional information and one method to calculate the induced voltage in a section of pipe.

### 6.3.2 Overhead and buried power lines

#### 6.3.2.1 General

Overhead power lines can generate unacceptable voltages onto buried pipelines, primarily by induction. The induction is a result of magnetic coupling. The magnitude of the induced voltage depends on the distance, length of parallelism, inducing current magnitude, frequency and phase relationship.

#### 6.3.2.2 Buried power cables

Buried power lines can generate unacceptable voltages onto buried pipelines, primarily by induction, in the same way as overhead power lines. It is preferable if buried cables are laid with the phase cables close to each other and formed in a trefoil configuration[4]. Trefoil formation refers to a method of arranging the individual phase cables to reduce the net inductance because the phases are in anti-phase and cancel each other.

#### 6.3.2.3 Railway systems

AC railway systems can be a source of interference. Where the pipeline is parallel to the railway, the coupling is primarily inductive. The rails of AC powered railways are earthed, and this can also result in conductive coupling to adjacent buried structures. AC railways can operate at 60 Hz, 50 Hz and 16,67 Hz. When evaluating the risks resulting from the effects of electromagnetic interference on buried pipelines running near AC electrified traction systems, the harmonic distortion in railway systems should be considered. The presence of harmonics can exacerbate voltages accumulating on buried pipelines[5].

## 6.4 High-voltage direct current transmission systems

There are two main configurations for high voltage direct current transmission systems, monopolar and bipolar. Bipolar HVDC systems should be given preference to avoid stray current interference. The earthing of HVDC systems shall be designed in such a way as to avoid current flowing through the earth during normal operation and to minimize earth current during faulty or unbalanced load conditions.

The entire system design shall consider the possible high-level of stray currents to which buried or immersed metal structures can be exposed to, even at a substantial distance from the electrode station.

Buried HVAC and HVDC cables are joined together in joint bays installed along the cable route. The separation distance between joint bays is dependent on the cable operating voltage, conductor size and construction. Not all joint bays will have an earth local to the joint bay, but the cable screens will be bonded in each joint bay. The location of all earths should be advised by the cable system operator. Where an operator decides to install an earth at a joint bay the earth should be installed at a distance from buried pipelines that will ensure that the touch voltage created on a pipeline during fault conditions is within safe limits. AC and DC leakage currents through earth systems can also result in interference on buried utilities and should be minimized.

Additional information is given in Annex E.

## 6.5 Natural interference

### 6.5.1 General

Natural low frequency interference is caused by geomagnetic field variations and by tidal water movements.

### 6.5.2 Geomagnetic (telluric) interference

Geomagnetic field variations are variations in the earth’s magnetic field. The geomagnetic field variations induce electric currents in the Earth and in long conductors such as pipelines and power transmission lines. These induced currents are generally referred to as telluric currents when related to pipelines and as GIC by the electric power industry. Both terms are used in literature and to be consistent with present pipeline practice this document will use the term telluric currents. (See Annex D for additional information).

### 6.5.3 Tidal interference effects

The movement of conductive seawater through the Earth’s magnetic field acts like a dynamo and generates an electric field in the seawater. This drives an electric current (a flow of charge) in the seawater, perpendicular to the direction of water movement. Where this electric current meets the land, there is a build-up of electrical charge that creates a potential gradient both along the seafloor and inland perpendicular to the coast. (See Annex G for additional information).

# 7 Identification and measurement of stray current interference

## 7.1 Principle

The identification of the stray current interference is achieved by analysis of the measurements. The evaluation of the interference is performed by a comparison of the data with the applicable criteria.

The measurements shall be planned to consider any known information relating to the interference acceptance criteria (Table 1 for DC). In particular, the following points should be considered:

- type of coupling of the interference (AC and/or DC);
- relative position to the stray current source (remote or nearby);
- anticipated duration of the anodic excursion ($T_{a,max}$);
- anticipated time dependence of the amplitude of $E_a - E_c$ as well as $J_a - J_c$ (Interference amplitude is constant or seasonally changing at constant $T_a$).

The measurement requires determination of the following:

a) the correct position for the reference electrode and/or coupons to be measured (See Annex B);

b) identifying the area of highest interference (Annex B);

c) Configuration of the coupon or probe (size and shape);

d) Connection of coupon or probe to the pipeline;

e) Sampling rate of the measuring system;

f) Duration of the measurements (see 7.3.6);

g) Switching ON/OFF ratio;

The evaluation of interference can be based on several different measurements at representative locations with respect to a reference electrode:

- structure potentials;
- current flowing through a coupon or probe;
- IR-free potential measurement of a coupon or probe;
- voltage between two reference electrodes;
- corrosion rate determined on a coupon or probe;
- line current measurement.

A description of the representative location for determining the relevant position for a simple situation is given in Annex B for the case of a conductive coupling.

Annex C provides information on the operational principles of the electrical resistance (ER) probe.

## 7.2 Stray Current interference

### 7.2.1 Inductive and conductive coupling from remote sources

The worst-case assessment of interference in the case of inductive coupling and remote conductive coupling is obtained when placing the reference electrode at remote earth. The method for determining remote earth is described in ISO 18086:2019, Annex G. Since inductive coupling is usually associated with high isolation quality of the interfered structure, the positioning of the reference electrode above the interfered structure can be used as an approximation of the remote earth.

In such a configuration, the probe should ideally be installed next to the pipeline in the same bedding material as the pipeline, outside the influence of any field gradients generated by coating defects.