Alternating Current (A.C) Corrosion of Burried Pipeline Principal Factors and Considerations

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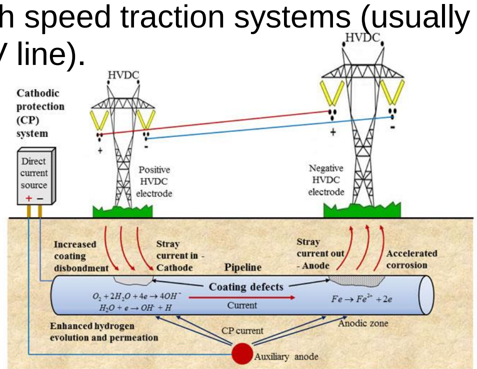
Interfering sources

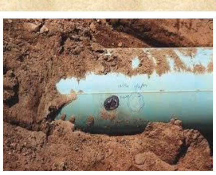
Main interfering sources for a.c. are:

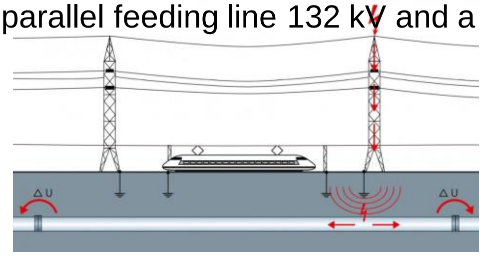
• high voltage aerial or buried power lines;

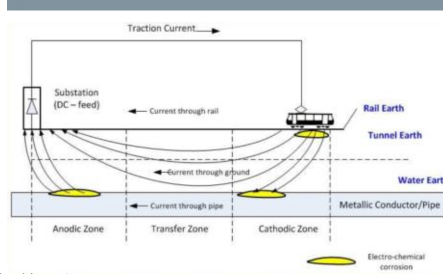
• long, parallel, power lines;

• high speed traction systems (usually fed by a parallel feeding line 132 kV and a 25kV line).









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Outline

- **Fault and Steady State AC corrosion**
- **Types of AC Corrosion**
- **Resistive coupling principal parameters**
- **Induced AC corrosion parameters**
- **Documented cases**
- **Basic mechanism of AC corrosion**
- **Basic parameters of AC corrosion of CP pipline**
- **AC corrosion risk criteria**
- **AC corrosion research**
- **Summary**

Ref.1:

Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring

NACE INTERNATIONAL

NACE SP21424-2018
Item No. 21424
Approved 2017 Dec

Ref.2:

A/C
Interference Guideline Final Report **JUNE 2014**
PREPARED BY:
R.A. GUMMOW, P.ENG, NACE CORROSION SPECIALIST NO.17 CORRENG CONSULTING SERVICE INC. 2-498 MARKLAND STREET MARKHAM, ONTARIO, L6C 1Z6, CANADA

CEPA canadian energy pipeline association | association canadienne de pipelines d'énergie

Ref.3:

Materials **2017**, 10, 851 , **Effect of Alternating Current on the Cathodic Protection and Interface Structure of X80 Steel**
https://www.mdpi.com/1996-1944/10/8/851/htm
Huiru Wang 1, Cuiwei Du 1,*, Zhiyong Liu 1, Luntao Wang 1 and De Ding 2
1 Corrosion & Protection Center, University of Science & Technology Beijing, Beijing 100083, China; huiruwangustb@163.com (H.W.); liuzhiyong7804@126.com (Z.L.); ltwangustb@163.com (L.W.)
2 Shanxi Electric Power Research Institute, State Grid Corporation of China, Xi'an 710054, China; dingde5160@163.com

Ref.4:

Energies 2018, 11, 2255 , Effects and Characteristics of AC Interference on Parallel Underground Pipelines Caused by **an AC Electrified Railway**
Minwu Chen 1,*, Siyang Liu 1, Jiuguo Zhu 1, Chonghao Xie 1, Hang Tian 1 and Jianjun Li 2
1 School of Electrical Engineering, Southwest Jiaotong University, Chengdu 611756, China; siyangliu@my.swjtu.edu.cn (S.L.); zhujiuguo_swjtu@163.com (J.Z.); xch9524@foxmail.com (C.X.); tianhang@my.swjtu.edu.cn (H.T.) 2 China Petroleum Pipeline Engineering Co., Ltd., Langfang 65000, China; cppelijianjun@cnpc.com.cn

Ref.5: https://www.matcor.com/ac-interference/

AC INTERFERENCE DAMAGE FOR PIPELINES

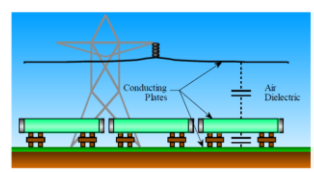
Under fault conditions, the AC interference could result in **damage to the pipe** itself (i.e. electrical arc between the structure grounding and the pipe), in **safety concerns** for pipeline personnel and in **damage to pipeline coating**, **isolation flanges and CP equipment**.

Under steady-state conditions, the AC interference could result in **safety problems** for people coming in contact with the metallic pipe or its appurtenances and in **accelerated corrosion** on the underground section of the pipe (i.e. AC corrosion).

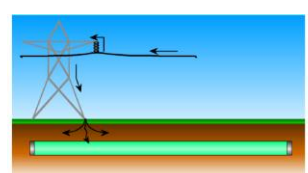
IMPORTANT!!! Personnel safety The 15 V limit was determined by multiplying 15 mA (considered the current limit below which a person could let go when grasping an electrified conducto and 1000 Ohm (conservatively considered the human body resistance assuming a contact resistance of zero ohms).

Ref.2:

There are **three modes of AC interference** that can cause damage to pipeline systems and present an electrical shock hazard to pipeline personnel

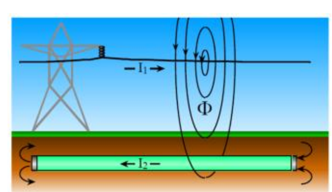


Capacitive (electrostatic) coupling is only a concern during construction when the pipe is elevated on skids and not in contact with the ground.



Resistive (conductive) coupling, only appears under powerline **fault conditions**.

The fault current flowing through the grounding of the high voltage structure (i.e. pole or tower) produces a potential rise in the neighbouring soil defined as "**ground potential rise**" (i.e. **GPR**). Part of this rise is transferred to the pipe and would be added to the AC induced voltage.



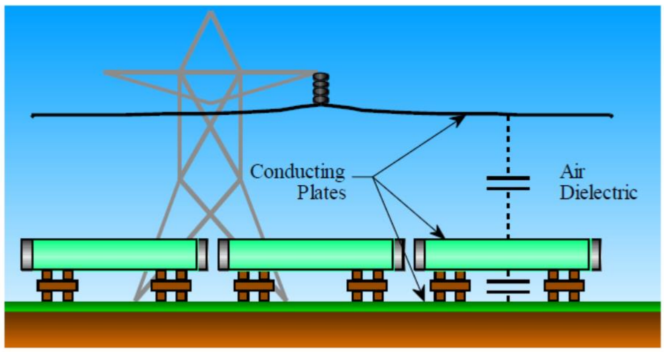
Inductive coupling occurs both under **steady-state (normal operation) and fault conditions** and the magnitude of the induced AC voltage depends on

-Phase current
-Length of co-location
-Distance between pipeline and powerline
-Pipeline-powerline configuration.

Note: the induced voltages reach maximum values at discontinuities and gradually attenuate along the pipeline.

Ref.2:

Capacitive (electrostatic) coupling is only a concern during construction when the pipe is elevated on skids and not in contact with the ground.



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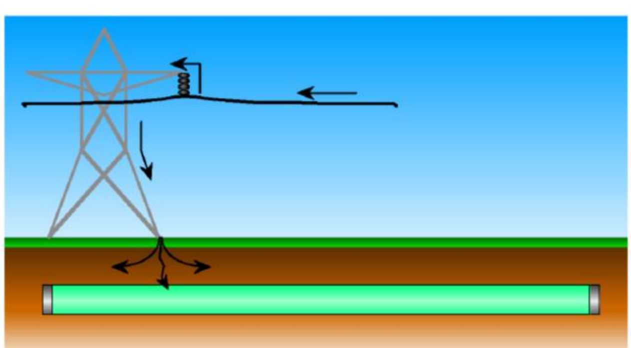


Ref.2:

Powerline faults typically occur during inclement weather such as high winds, ice storms, or electrical storms

If a pipeline is in proximity to the foundation or grounding of a faulted powerline structure, there is a risk of an **arc developing** from the powerline grounding to the pipeline (**resistive coupling**), which could result in damage to the pipe wall and/or the coating.

Even **without arcing** , when the fault current is discharged to the ground via the tower foundation or via grounding electrodes the potential of the ground rises several thousand volts **(ground potential rise or GPR**), which can result in a large potential differential between the pipeline and the ground, most of which appears across the coating.

Note: AC fault current can transfers through the **coating and coating holidays**, resulting in a portion of this GPR voltage being transferred to the pipe (resistive coupling). Furthermore, if the powerline and the pipeline are parallel, significant voltages can be induced in the pipeline by the fault current (inductive coupling).

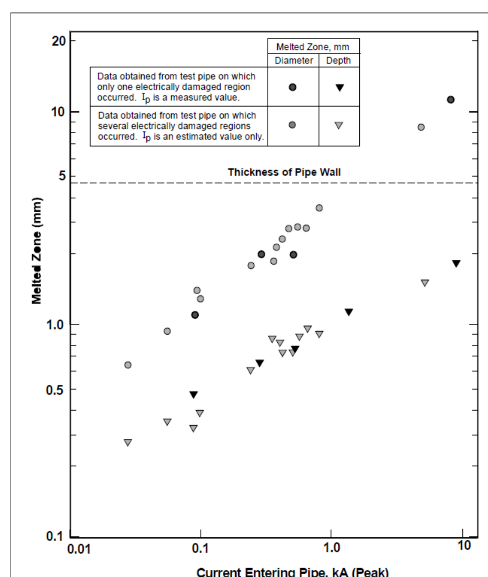
Ref.2:

An arc to the pipeline can transmit enough power to **melt the wall** of the pipe wall

A melted spot on a pipe wall can be a problem even in the absence of a perforation, since there will be a **heat affected zone** and rapid cooling after the fault can create a hardened surface that is susceptible to **cracking and hydrogen embrittlement**.

Diameter and Depth of Melted Area vs. AC Current

Drakos[2] conducted field fault tests on 35 mm diameter coated steel pipe placed near a 230 kV line. The maximum test fault current was **7.8 kA in 100 Ohm-m clay**. It was found that there was a linear relationship between the fault current magnitude and both the depth and diameter of the melted area



Ref.2:

Coating Stress

A **fault condition** that does not melt the pipe wall can still cause **coating damage** depending on the fault voltage appearing across the coating and the dielectric strength of the coating material. Typical dielectric strengths of various insulating materials are shown in Table 1.

Dielectric Strength as a Function of Coating Material

Coating Type	Dielectric Strength
Polyethylene	18.9 kV/mm
Epoxy Resin	19.7 kV/mm
Polyurethanes	~25.0 kV/mm
Enamels	47.4 kV/mm

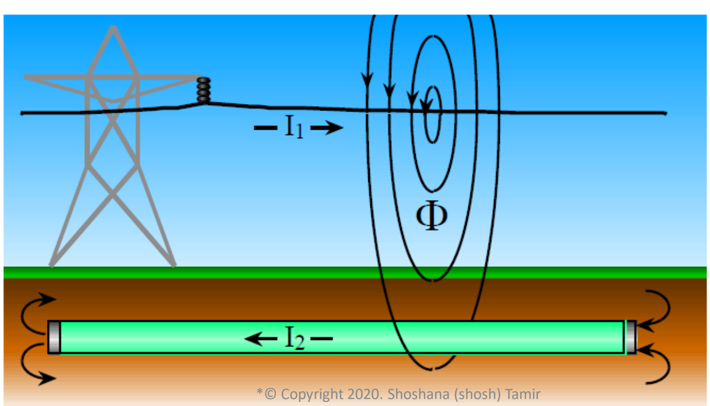
Coating Puncture Voltage Levels

Coating Type	Voltage Level V/mSec
Fusion Bonded Epoxy	1000 v/mil
Coal Tar Epoxy	3500 v
Coal Tar	4500 v
Coal Tar Enamel	5000 v

Ref.2:

Electromagnetically Induced Current in a Pipeline

Every phase conductor of every circuit on one or more powerlines, which parallel the pipeline, produces a magnetic field, the strength of which is directly dependent on the magnitude of the individual phase current and inversely proportional to the distance between phase conductor and the pipeline.

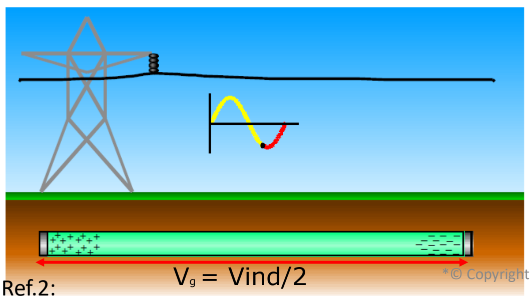


Ref.2:

Phase conductor currents can range from several hundred amperes to 2000 A.

The resulting current in the pipe appears as a result of only the net magnetic field produced by all the phase conductors.

The induced alternating current in the pipeline produces a longitudinally induced voltage (Vind) along the length of the pipeline, such that the voltage at each end of the pipe is 180º out of phase, as shown in the figure below



Ref.2:

The magnitude of the **induced voltage** is **directly** proportional to the
- **phase current**,
- **length of parallelism**,
- **resistance of the pipe coating**,
- **resistivity of the earth**,

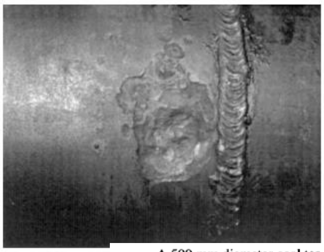
and **inversely** proportional to the **distance** between the pipe and the phase conductor.

Documented cases

Observations of AC corrosion on cathodically protected pipelines were reported in the early 1990s in Europe, which prompted research investigations confirming that at certain AC current densities, AC corrosion could be expected to occur on cathodically protected pipelines.

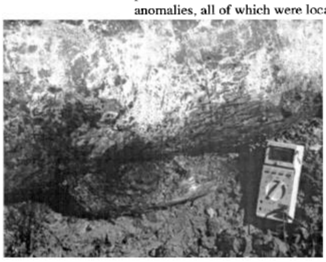
AC corrosion of steel pipelines which share a common right-of-way (ROW) with a high voltage powerline in Toronto

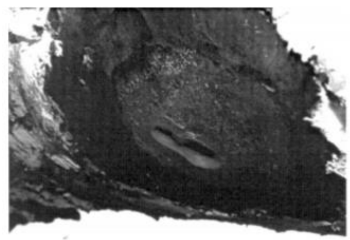
High pressure gas pipeline coated by coal tar



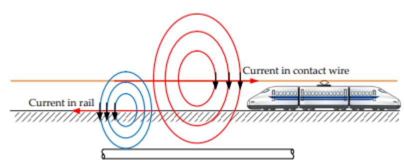
Case 1
1991

A 500 mm diameter coal tar coated high pressure natural gas pipeline was installed in 1972 by Union Gas. Approximately 40 km of this 74 km long pipeline were parallelled by a high voltage AC power line. In 1995, an internal inspection using an ultrasonic inspection tool identified a number of anomalies, all of which were located along the power line right-of-way. Defects estimated to have a





Case 2
1995



(a)

Before cleaning

(b)

After cleaning

2006??

During a routine inspection of a natural gas transmission line in Canada, it was found that a leak occurred at the end of a pipeline runs in parallel to a railway (16 2/3-Hz system) for approximately 10 km

Ref. 4

The mechanism of AC corrosion involves one or more of the following processes

4.5.1 Lack of passivity due to the fast cycling of the potential across the immune/passive stability line of steel on the Pourbaix diagram. The corrosion process is fast and can occur within the period of an AC cycle, whereas subsequent passivation requires the formation of ferrous oxides or hydroxides. These processes are slower and may not run to completion within the period of an AC cycle.

4.5.2 Cycling of the potential between the regions of stability of protecting and non-protecting ferrous oxides and –hydroxides, the result of which is a net oxidation of the steel.

4.5.3 Extreme alkalization at the coating defect due to the AC corrosion cycle described. The very high pH values at the coating defects, combined with the AC may reach the critical high-pH corrosion area in the Pourbaix diagram, favoring corrosion by the formation of $HFeO_2^-$.

4.5.4 Thermal heating due to the exchange of high AC current densities has been reported to be a potential source for increasing the risk of AC corrosion. Increased soil conductivity and reaction kinetics are generally expected during local soil heating, and bubble formation as well as local soil dry out may occur.

Ref. 1

AC corrosion Basic parameters:

- **AC voltage**
- **Cathodic protection**
- **Defect size**
- **chemical composition of soil**

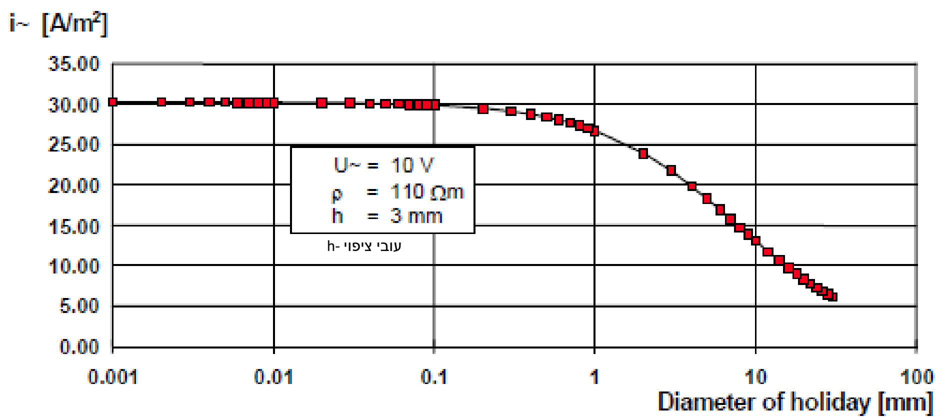
under the influence of alternating current. AC corrosion on cathodically protected underground pipelines is commonly the result of a combined action of the AC voltage, the cathodic protection conditions, a coating defect—usually small—and the chemical and physical conditions of the soil. If the AC component is either entirely removed or limited to a certain level, the corrosion will be mitigated.

The combined effect of AC Induced Current and Cathodic Protection

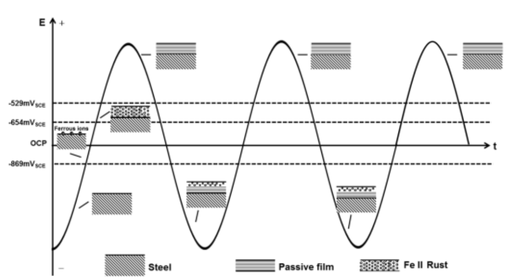
Excessive cathodic protection (CP): Cathodic protection levels that lead to cathodic protection DC current densities exceeding 1 A/m^2 or cathodic protection levels that lower the spread resistance due to cathodic reactions.

Ref. 1

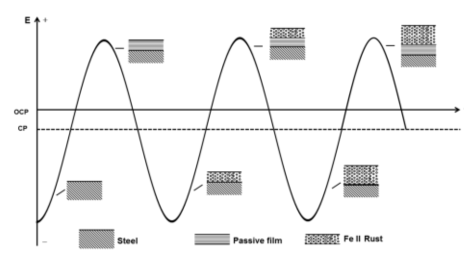
Small defect



pH:9.6



Sketch map of the AC corrosion process occurring on X80 steel in the absence of CP current.



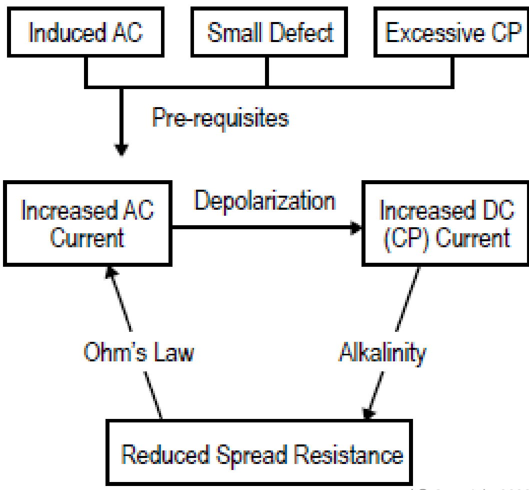
Sketch map of the AC corrosion process occurring on X80 steel in the presence of CP current.

Table 1. Chemical compositions of X80 (wt. %).

Material	Fe	C	Mn	Si	S	Cr	Ni	Cu	Al	Ti	Mo	V	Nb	N
X80	96.933	0.036	1.771	0.197	0.002	0.223	0.278	0.22	0.021	0.019	0.184	0.001	0.11	0.005

Ref.3

Autocatalytic Nature of AC Corrosion on Cathodically Protected Pipelines



4.1.1 The induced AC will lead to the discharge of AC current at coating defects, the intensity of which (AC current density) is measured in A/m².

4.1.2 The AC current density will be governed by the AC voltage (coating stress voltage) and the spread resistance, associated with the coating defect, through Ohm's Law.

4.1.3 The spread resistance is governed by the size of the coating defect, the soil resistivity at the coating defect, the chemistry of the soil, and by the cathodic protection current density in the coating defect.

4.2 The AC current density may lead to DC depolarization. This means that a higher CP (DC) current density is required to maintain a certain cathodic protection potential.

4.3 Increasing the level of cathodic protection may be attempted in order to mitigate AC corrosion. However, in the AC corrosion scenario, this will have the opposite effect, since the increase of CP current density further decreases the spread resistance at the coating defect due to the production of ions such as OH^- (alkalization). It is noted that the spread resistance may also increase rather than decrease under CP conditions as a result of the formation of high resistive films, such as magnesium- or calcium hydroxides or -oxides, on the steel surface at elevated pH conditions, if these earth alkaline cations are present in the soil. These conditions then lead to a decreased AC corrosion risk.

Ref. 1

RISK ASSESMENT

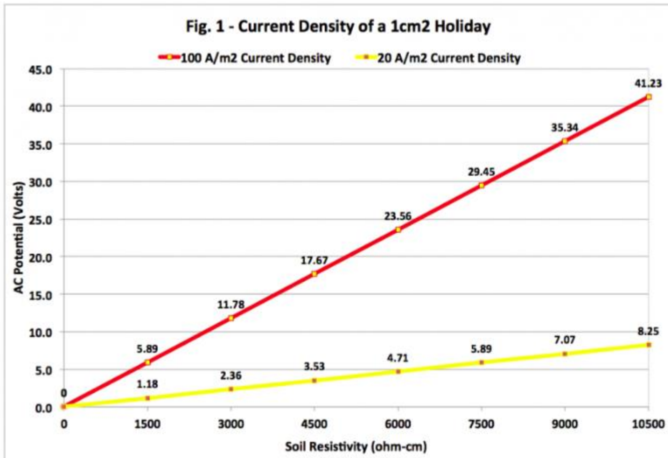
Initial analysis on existing pipelines can be performed in order to gain an initial impression on the risk of AC corrosion or in order to identify if supplementary investigations or analysis are required. The initial analysis may comprise the following:

5.4.2 **AC Voltage Measurements:** Generally, the risk of AC corrosion increases with increasing AC voltage even though it has been observed that even at low AC voltages (<1V), AC corrosion can occur if the spread resistance and/or bulk soil resistivity is very low. This is, however, an extreme condition. Furthermore, regardless of the AC voltage level, high resistivity soils will generally result in low AC current density and subsequently lower the risk of AC corrosion.

5.4.3 **DC Cathodic Protection Potential:** AC corrosion may result from the case of inadequate or excessive CP present on a pipeline. If significant pipe metal voltage drops occur due to the pipeline current, it should be considered to further investigate this in combination with the above AC voltage observations.

Ref. 1

AC Interference and Pipeline Corrosion



What this chart shows is that ***pipelines with induced AC voltage and good quality coatings are at risk for significant external corrosion often at AC levels well below the 15V AC threshold that has historically been used as a benchmark value for personnel safety considerations***. With low resistivity soil environments, corrosion can be a risk at much lower steady state AC values.

Ref. 5

AC corrosion criteria

Despite numerous research studies, the **AC corrosion mechanism is still not well understood**, and **empirical results** must be used to assess the AC corrosion risk for cathodically protected pipelines.

From these early studies, guidelines relating the probability of AC corrosion to AC current density and also the ratio of AC current density to CP current density were derived as shown in Tables below

AC Corrosion Probability on a Cathodically Protected Steel Pipeline based on AC Current Density (i_{ac})

AC Current Density	AC Corrosion Probability
$i_{ac} \leq 20A/m^2$	Low
$20A/m^2 < i_{ac} < 100A/m^2$	Unpredictable
$i_{ac} > 100A/m^2$	Expected

AC Corrosion Probability on Cathodically Protected Steel Pipelines based on i_{ac}/i_{dc} Ratio, European Standard EN 12954

I_{ac}/i_{dc} Ratio	AC Corrosion Probability
$i_{ac} / i_{dc} < 5$	Low Likelihood
$5 \geq i_{ac} / i_{dc} \leq 10$	Moderate Likelihood
$i_{ac} / i_{dc} > 10$	High Likelihood

Ref. 2

Summary

AC corrosion studies- Basic Findings

•AC induced corrosion occurs on both cathodically protected and unprotected pipelines and other structures

•The rate of corrosion diminishes over time

•The optimum holiday size for AC induced corrosion is 1 cm^2

•The rate of corrosion increases in de-aerated soils or soils with high chloride content

•Corrosion can be expected at current densities in excess of 100 A/m^2 and has been observed at current densities as low as 20 A/m^2

•AC corrosion Increase with decreasing of AC frequency- Below 100Hz

Thank You