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United Kingdom Onshore Pipeline Operators' Association

Good Practice Guide

D.C. Interference Guidelines

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The guidance in this document represents what is considered by UKOPA to represent current UK pipeline industry good practice within the defined scope of the document. All requirements should be considered guidance and should not be considered obligatory against the judgement of the Pipeline Owner/Operator. Where new and better techniques are developed and proved, they should be adopted without waiting for modifications to the guidance in this document.

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EXECUTIVE SUMMARY

This Good Practice Guide (GPG) is intended to give guidance to pipeline operators on the management of d.c. stray current interference on pipelines. It has been prepared to provide advice on the testing, design, monitoring and mitigation of direct current (d.c.) stray current interference on cathodically protected steel pipelines. It also provides information on the effects of d.c. current flow in pipelines on internal corrosion risks and pipeline instrumentation systems.

This GPG provides information to pipeline operators on applicable standards and published literature in relation to d.c. interference on metallic pipelines. It is not intended to provide specific guidance on d.c. stray current interference on electrical cables, marine or reinforced concrete structures.

The GPG provides guidance on how to mitigate and monitor the interference risks on pipelines caused by d.c. electrical systems that can produce stray current.

This document has been based upon the recommendations and guidance given in BS EN ISO 21857 [1], which will replace BS EN 50162 [2]. It also supplements the guidance given in UKOPA/GPG/014 [3] in relation to d.c. stray current interference from solar farms.

This GPG describes the stray current interference effects of d.c. traction systems on buried pipelines but also identifies several other sources and causes of d.c. stray current interference on pipeline systems namely Photo Voltaic (PV) farms, high voltage direct current (HVDC) power systems, d.c. instrumentation systems and d.c. welding operations.

This document provides guidance on the design of d.c. interference mitigation systems plus gives information on the protection criteria that should be adopted on pipelines affected by d.c. interference.

Detailed information on d.c. traction systems and the specific interference issues associated with d.c. traction systems is given in Appendix C of this GPG. The information on d.c. traction systems is given in an Appendix to this GPG, as d.c. traction system interference may not affect pipelines operated by some UKOPA members.

D.C. stray current corrosion can occur in certain circumstances and if the interference risk is not managed it can result in high rates of metal loss on cathodically protected and non cathodically protected pipelines, which can affect pipeline integrity.

Information is given in this GPG on the recommended maintenance procedures that should be followed together with the nature and frequency of the tests that should be conducted on pipelines susceptible to d.c. interference.

It is important that personnel involved in the design, operation and maintenance of pipelines are fully aware of the consequences of both managed and unmanaged d.c. stray current interference and ensure that any d.c. stray current interference risk is effectively monitored, managed and mitigated.

1. INTRODUCTION

1.1 Background

This document has been prepared to provide pipeline operators with guidance on the control and management of the d.c. stray current interference risk on pipelines. The requirements in relation to evaluation and management of alternating current (a.c.) interference and a.c. corrosion risks on buried pipelines and the protection criteria to mitigate a.c. corrosion risks are defined in BS EN ISO 18086 [4], UKOPA/GPG/027 [5] and in relation to the a.c. and d.c. interference risks from solar farms in UKOPA/GPG/014 [3].

The safety aspects associated with a.c. interference on pipelines from a.c. power lines and traction systems are detailed in BS EN 50443 [6] and are supplemented by the guidance given in UKOPA/TBN/005 [7].

This document is intended to provide information to pipeline operators, designers, promoters of new works within the vicinity of pipelines and other relevant organisations on the requirements to minimise and manage the risk of d.c. stray current interference on buried metallic pipelines. This GPG is intended to expand upon the information provided in existing standards. It provides supplementary information on the effects that d.c. current flow in pipelines and pipework can have on the internal corrosion risk at isolation joints (I/Js) or insulated flanges (I/Fs) on pipelines containing a conductive fluid, the effect that d.c. current flow in pipelines can have on instrumentation systems and also the incendive ignition risks associated with d.c. current flow in earthing systems and pipelines.

1.2 Scope

The guidance in this document is applicable to all buried steel or corrosion resistant alloy pipelines and pipework operated by UKOPA members. It provides information on the latest good practice guidance for design, construction, operation and maintenance of d.c. interference risks.

This GPG provides information on the design of d.c. stray current interference monitoring and mitigation systems on new and existing pipeline systems. It also addresses the operation and maintenance requirements for pipelines susceptible to d.c. interference, so that any accelerated corrosion risk can be managed.

1.3 Application

The document is considered by UKOPA to represent current UK pipeline industry good practice within the defined scope of the document. All requirements should be considered to be guidance and should not be considered to be obligatory against the judgement of the pipeline Owner/Operator. Where new and better techniques are developed, or new normative standards are produced they should be adopted without waiting for modifications to the guidance in this document.

Within this document: **Shall:** indicates a mandatory requirement

Should: indicates good practice and is the preferred option

2. DC INTERFERENCE

2.1 General

D.C. stray current interference from pipeline cathodic protection systems, d.c. traction systems, industrial d.c. power systems or d.c. welding operations during pipeline construction and repair can result in high rates of corrosion on metallic pipeline systems. If not effectively controlled and managed. d.c. stray current interference can have a serious impact on the integrity of a pipeline system.

The term interference refers to the electrical disturbance caused by stray current. Stray current is defined as current in an unintended path. Thus, any d.c. operated electrical system in contact with the earth is a source of stray current.

The following sub-sections discuss the effects of d.c. stray current interference. Detailed guidance on measures to control d.c. stray current interference on pipeline systems are provided in BS EN ISO 21857 [1]. It should be noted that BS EN ISO 21857 replaces BS EN 50162 [2] and at the time of publishing this GPG BS EN 50162 was current.

2.2 D.C. Stray Current

Whenever there is current flow in the earth, from whatever source, a piece of metal buried in the earth may function as a part of the current path, collecting current over a part of its surface and discharging it with attendant corrosion from another part.

This may be demonstrated by the case of a 'secondary' structure or pipeline passing within the influence of a cathodic protection impressed current groundbed installed on the primary structure. Here, current from the groundbed may utilise the secondary structure to return to the cathodic protection power source, most likely discharging from the secondary structure at its crossing point with the primary protected structure see Figure 1.

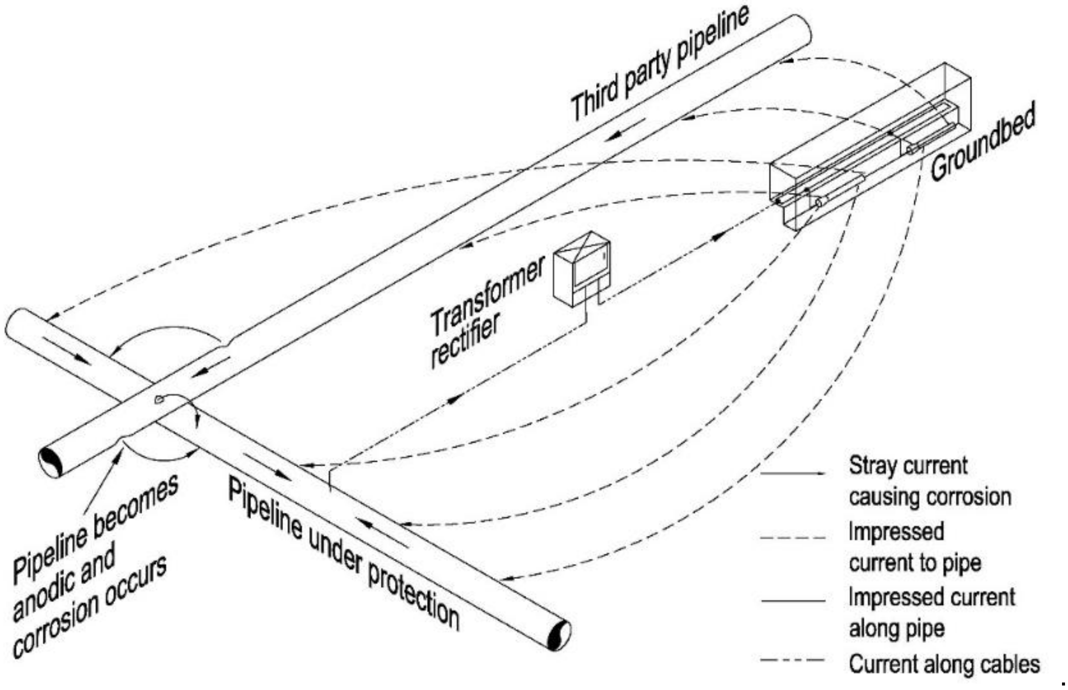

Figure 1. Stray Current Interaction at a Pipe Crossing

In Figure 1 the condition whereby, there is a detrimental d.c. interference problem is characterised by pipe to soil potential changes at the crossing point of the secondary structure when the cathodic protection system is energised. Changes in pipe to soil potential, which tend to produce an anodic condition can result in accelerated corrosion and need to be controlled. Metal loss may occur at the anodic current discharge locations.

No corrosion should be experienced on the third-party pipeline in the vicinity of the groundbed shown on Figure 1 as the pipeline will be cathodically protected at that location, since current would enter the pipeline at this point. However, in certain instances where current enters a pipeline there may a cathodic disbondment risk or on susceptible materials e.g. high tensile strength steels or certain corrosion resistant alloys (CRAs) a hydrogen induced cracking risk. D.C. current will then flow along the pipeline until it finds a suitable location to leave the pipeline, normally at a coating defect at a pipeline crossing with a third-party pipeline. Figure 1 shows the effect that may happen when pipeline systems are affected by cathodic protection (CP) systems installed within the vicinity of buried pipelines.

Stray d.c. current will attempt to find the lowest resistance path back to the d.c. power source. Where d.c. current leaves a pipeline to return to its power source e.g. at a coating defect the pipeline can be made anodic and accelerated corrosion may occur. The rate of corrosion will be dependent upon the magnitude of the d.c. current density discharge and direction of the d.c. current leakage. Stray currents can be beneficial or detrimental to a pipeline.

A positive change of potential should be considered as d.c. interference, as is evident from Figure 2 and would occur at a current discharge location. The extent of any corrosion or risk of cathodic disbondment on a pipeline coating is dependent upon the magnitude of the potential shift and d.c. current density at the current discharge or collection location. Figure 2 shows the potential shift on a pipeline due to the operation of a foreign pipeline's CP system or other source of d.c. stray current. Point 'A' represents a cathodic shift, whilst point 'B' represents an anodic shift. The anodic shift may result in pipeline corrosion, whilst the cathodic shift may cause disbondment of a pipeline's coating. At anodic sites accelerated corrosion can occur.

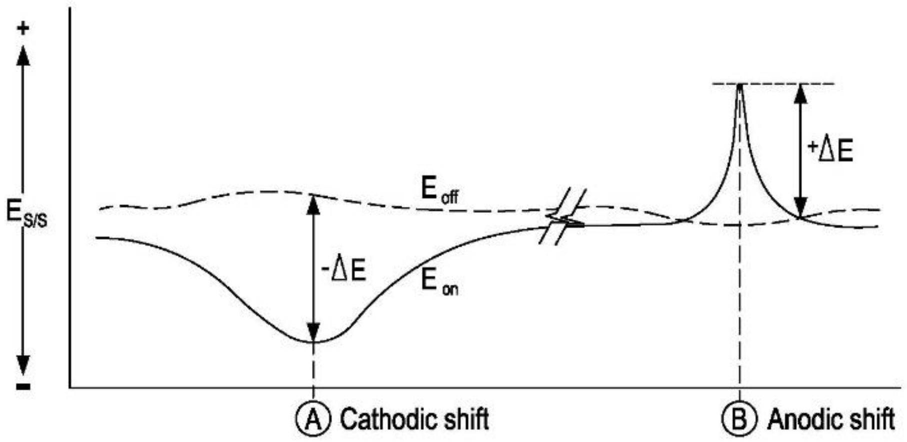

Figure 2 Schematic of Potential Shift in Stray Current Interference Location

At the area of current pick-up, a negative shift in the structure potential will occur and result in cathodic polarisation. In the case of foreign pipelines affected by stray current interference there is generally a beneficial effect as the structure will receive some measure of cathodic protection.

However, if the structure namely a pipeline is coated or already under cathodic protection the additional polarisation from the stray current pick-up may result in cathodic disbondment of the pipeline coating.

Indeed, if excessive pipe to soil potentials are achieved e.g. in the case of steels with a yield strength in excess of 550MPa or on pipelines constructed from a CRA, that is susceptible to hydrogen induced stress cracking (HISC) e.g. martensitic, duplex or super duplex stainless steels excess levels of cathodic polarisation may result in an enhanced cracking risk.

The potential criteria associated with cathodic polarisation, including cathodic disbondment and HISC on susceptible materials are discussed further in Section 5.

2.3 Corrosion Mechanism

At locations where d.c. stray current enters a structure then the potential of the structure will be reduced, and the pipeline potential moved in a cathodic direction. For pipelines buried in soil the application of cathodic protection removes oxygen dissolved in the soil moisture as shown below:

$$\mathbf{O_2 + 2H_2O + 4e^- \rightarrow 4OH^-} \qquad \mathbf{1)}$$

Equation 1) is the primary cathodic reaction that occurs in soils, where the pH range is in the region of 5 to 9.

The removal of oxygen causes the pH at the steel surface to increase and become more alkaline. If a sufficient negative change in potential occurs at the current entry location, then the potential criteria detailed in Table 1 of BS EN 12954 [8] to achieve cathodic protection, may be achieved and effective levels of cathodic protection could be obtained, and the pipeline will be protected from corrosion. The cathodic reaction at the surface, where the current enters a non cathodically protected structure, lowers the corrosion rate on a non cathodically protected structure, which otherwise would be higher due to the corrosive influence of the surrounding environment. On a cathodically protected structure it will increase the levels of cathodic protection afforded to the pipeline, which may create issues with maintenance of acceptable levels of cathodic protection on a pipeline.

The magnitude of potential change at the current entry point will determine the reduction in corrosion rate and if the potential change is excessive then cathodic disbondment of the pipeline coating can occur. BS EN ISO 15589-1 [9], advises that to prevent disbondment and/or blistering of a pipeline coating, the limiting critical instant OFF potential, should not be more negative than −1,20 V vs $Cu/CuSO_4$ for the currently used pipeline coatings. At excessive cathodic current densities, decomposition of water takes place leading to evolution of hydrogen and production of hydroxide ions.

$$\mathbf{2H_2O + 2e^- \rightarrow 2OH^- + H_2\uparrow} \qquad \mathbf{2)}$$

The production of hydroxide ions increases the pH on the metal surface, which may result in disbondment of organic protective coatings from the metal surface at coating defects due to hydrogen evolution and saponification of the pipeline coating by the alkaline conditions created at the coating to steel interface, which can affect the coating to steel adhesion.

In the case of stray current interference, the magnitude of the current entering the affected structure cannot often be controlled. Stray current will always try and find the lowest resistance path to return to its power source.

Current will flow along the affected structure and will discharge at a suitable location or locations e.g. at the crossing of a railway line or third-party pipeline. Where current discharge occurs then the pipe to soil potential will move in a positive direction i.e. there will be a positive shift in potential caused by the current discharge at a coating defect.

At the point where the stray d.c. current leaves the metal structure an anodic corrosion reaction may take place at the metal/electrolyte interface, resulting in oxidation (dissolution) of the metal. In the case of a steel pipeline the following anodic electrochemical reaction will take place and oxidation of the steel will occur.

$$Fe \rightarrow Fe^{2+} + 2e \qquad 3)$$

The dissolution (mass loss) follows Faraday's law, which for a bare iron or steel surface means that an anodic current (current leaving the surface) $I_{D.C.}$ = 1 A will dissolve approximately 9.1 kg of Iron per year.

Expressed as corrosion (average penetration of the steel surface) if the anodic current density $J_{D.C.}$ = 1 Am^{-2} then this will result in a corrosion rate of 1.1 mm per year of iron. This corrosion caused by a current originating from an external d.c. current source is known as stray current corrosion.

The corrosion rates indicated above will only occur if the anodic reaction is under activation control and does not result in passivation of the steel surface and an alternative anodic reaction e.g. oxide formation or oxygen evolution occurs. All the current needs to result in metal dissolution, if that is the case then 9.1 kg of steel will be lost for every Amp that flows during the course of a year, if alternative reactions occur the rate of metal loss will be lower.

From Table 1 it can be seen that there only needs to be a limited d.c. current flow off a pipeline at a coating defect to result in an appreciable accelerated corrosion rate on mild steel. In the case of pipelines, the current flow will be at the site of a coating defect and will only occur if there is detrimental d.c. stray current interference. The corrosion rate on a pipeline will be determined by the d.c. discharge current density at the current discharge location.

The corrosion rates given in Table 1 are the average corrosion rates and not the pitting or localised corrosion rates that could occur if a pipeline was subject to stray current interference. The localised pitting rate could be higher than the general corrosion rate.

D.C. Current Flow Off 1cm^2 Coupon mA	D.C. Current Density (Am^{-2})	Corrosion Rate (mm per year)
0	0	0
0.1	1	1.1
1	10	11
5	50	55
10	100	100
50	500	500
100	1000	1100

Table 1. Corrosion rate on a steel coupon of exposed surface area 1 cm^2 expressed as corrosion rate in mm per year for different anodic discharge current densities.

The pitting corrosion rate could be 3 to 5 times the general corrosion rate. The corrosion rates given in Table 1 consider that all current flow results in metal loss, which may not always be the case as alternative anodic reactions may occur.

DIN 50526 Part 3 [10], gives typical soil corrosion rates on steel in the absence of CP for different soils.

BS EN ISO 15589-1 advises that the pipe-to-electrolyte potential at which the corrosion rate is less than 0,01 mm per year for carbon steel is termed the protection criterion or E_P. BS EN 12473 [11], also advises that cathodic protection is an electrochemical corrosion prevention system based on the decrease of corrosion potential to a level at which the corrosion rate of the metal is significantly reduced (BS EN ISO 8407 [12]). For industrial structures, residual corrosion rates less than 10 µm/yr are typically achieved with a fully effective cathodic protection system.

Higher corrosion rates in excess of 0.01 mm per year can occur on pipelines where the d.c. stray current interference risk is not controlled. In the case of d.c. stray current interference, the soil resistivity dictates the resistance to remote earth at a coating defect. The lower the defect spread resistance the higher would be the d.c. discharge current density at a given defect for a given pipe to soil potential

Thus, where pipelines are subject to d.c. interference the corrosion risk will be greater in lower resistivity soils. When d.c. stray current interference discharges off a structure a positive potential shift due to stray current interference will mean that the effective d.c. current density flowing to the pipeline is being reduced. The magnitude of the positive change in potential on switching the d.c. stray current source will indicate the severity of the interference. If the direction of the current flow changes and current actually leaves the pipeline, then net metal loss may occur.

Stray current can cause accelerated steel metal loss with corrosion rates dependent upon the surface area over which current discharges. If the metal loss occurred over a small area it can result in an appreciable localized pitting corrosion rate in terms of mm per year (see Table 1). Figure 3 shows the nature of a metal loss feature on a pipeline as a result of d.c. stary current interference. These defects tend to occur as relatively small, localised defects or metal loss features.

Figure 3 Picture of external metal loss feature on a pipeline that occurred as a result of d.c. stray current interference.

2.4 Corrosion Rates in Soil in the Absence of CP

It is considered prudent to provide some guidance on the typical corrosion rates that can occur on steel pipelines in soil in the absence of CP and d.c. stray current interference.

Table 2 extracted from DIN 50526 Part 3 [10] gives typical soil corrosion rates on steel in the absence of CP for different soils. High corrosion rates can occur on pipelines where the d.c. stray current interference risk is not controlled. The corrosion rates given in Table 2 are for non cathodically protected steel pipelines i.e. with no CP applied.

Soil Aggressiveness	General corrosion rate (mm/yr)	Localised attack (mm/yr)	Soil Resistivity Range (Ohm m)
Virtually non-aggressive	0.005 (range 0.0025 to 0.01)	0.03 (range 0.015 to 0.06)	➢ 300
Weakly aggressive	0.01 (range 0.005 to 0.02)	0.05 (range 0.025 to 0.1)	100 to 300
Aggressive	0.02 (range 0.01 to 0.04)	0.2 (range 0.1 to 0.4)	25 to 100
Strongly Aggressive	0.06 (range 0.03 to 0.12)	0.4 (range 0.2 to 0.8)	< 25

Table 2. Assignment of Aggressiveness and Expected Free Corrosion Rates for Soils (After DIN 50 929 Part 3, 1985)

BS EN 12501-1 [13] and BS 12501-2 [14] provide guidance on the assessment of corrosion rates in soils and the factors that affect corrosion rate but do not give any data on the corrosion rates that are likely to be experienced.

When d.c. stray current interference discharges off a structure a positive potential shift due to stray current interference will mean that the effective cathodic d.c. current density flowing to a pipeline is reduced if the structure potential change is significant this could result in anodic current discharge.

The magnitude of the positive change in potential on switching the d.c. stray current source will indicate the severity of the interference. If the direction of the current flow changes and current leaves the pipeline, then net metal loss may occur

Stray current can cause accelerated metal loss with corrosion rates dependent upon the anodic current density at the surface over which current discharges. If the metal loss occurred over a small area it can result in an appreciable localized pitting corrosion rate in terms of mm per year (see Table 1).

The pitting corrosion rate of steel in soil in the absence of CP could be 3 to 5 times the general corrosion rate.

3. INFORMATION EXCHANGE AND CO-OPERATION

3.1 New Works

Promoters of new developments that may cause d.c. stray current interference should notify pipeline operators at the time that a development is planned. Pipeline operators should also ensure that information on new developments is passed to personnel within the operator's organisation with the requisite technical knowledge to assess if there may be any d.c. or even a.c. stray current interference risks associated with a proposed development before permission for any new development is granted. In the case of new PV farms, the guidance given in UKOPA/GPG/014 [3] Edition 1 should be followed in addition to the guidance given in this GPG.

In the case of new HVDC power cable systems, rail traction systems, cathodically protected pipelines and other sources of d.c. current the stray current interference risk should be assessed.

For new HVDC power cable crossings of pipelines then operators need to establish where the substation to which the power cables will terminate is located and then confirm where the overhead or buried power cables from the new substation are routed. If the cables are routed close to an operator's pipelines or at a substation close to an operators pipeline then the additional load on the overhead power cables in the vicinity of the development could be significant and could also affect the a.c corrosion and interference risk on existing buried pipelines for some distance from the proposed development.

Guidelines on appropriate action in such circumstances are given in UKOPA/GPG/027 [5].

In the case of new d.c. traction systems or extensions to existing traction systems promoters of the new works need to contact owners of buried metallic utilities in the area at the design stage. This is to establish the pipeline operators' requirements and agree measures to assess, mitigate and monitor the d.c. interference risks.

Planning application procedures for new developments within the vicinity of pipelines should follow the guidance given in UKOPA/GP/029 [15]. and include an assessment on the residual risks to buried metallic utilities when permission is granted.

This is particularly important in the case of new railway developments, solar farms, pipelines and HVDC power cable systems.

3.2 Design and Information exchange

During the design stage of buried or immersed metallic structures the possibility of both causing and suffering from d.c. stray current interference should be taken into consideration, in order to ensure that the pipe to soil potential criteria for pipeline systems that are specified in Section 5 are satisfied.

A review of possible situations that may lead to stray current interference should be undertaken e.g. construction activities, major changes on existing structures, sources of d.c. stray current interference that may result in an interference situation or affect the levels of cathodic protection afforded to buried pipeline systems.

HSG 47 [16] gives guidance to promoters of new works on identifying and managing the dangers to buried services and detecting, identifying and marking underground services. It is essential that Promoters of new works that may cause a d.c. stray current interference risk take steps to prevent damage to all metallic underground services.

In relation to buried pipelines Regulation 15 of the Pipelines Safety Regulations [17] requires that *No person shall cause such damage to a pipeline as may give rise to a danger to persons.* Thus, promoters of new stray current systems have statutory requirements to mitigate the damage that may be caused to pipelines from d.c. stray current systems.

Electrical interference issues on buried or immersed metallic structures should be considered these include the location of possible d.c. current sources e.g. third-party pipeline groundbeds, solar farms, HVDC systems and it should be determined whether there is a known problem with d.c. interference on an existing pipeline system or if there is any a.c power source associated with any new development e.g. PV farm or HVDC converter station. that may create an electrical hazard on existing pipelines.

In routing of new pipelines or undertaking diversions on existing pipelines it is important to ascertain the precise location of any third party or pipeline operator groundbeds to ensure that they will not create a stray current interference risk on the new development. It is also important to establish whether d.c. stray current interference is already a risk to an existing pipeline system.

BS EN 50162 [2] advised that “The goal of managing d.c. interference risks is 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 pipeline CP system. In this way possible effects, suitable precautions and remedies can be assessed”.

The following information should be exchanged:

1) Details of buried metallic structures,

2) Detail on cathodic protection installations, groundbed, CP test facilities or significant modifications to existing installations.

3) D.C. traction system installations or significant modifications to existing installations.

4) HVDC transmission line installation or modification to existing installations.

5) Details of any sources of d.c. current that can cause interferences to buried pipelines (e.g. UPS systems, solar farms, industrial facilities, battery energy storage sites and HVDC systems etc.)

Agreement and co-operation may be more effectively achieved and maintained by periodic meetings between interested parties, committees or other associations who can establish information exchange procedures and protocols. It is important that relevant information is considered in a timely manner and during the planning or conceptual design stage of any new pipeline system or d.c. power system.

Indeed, when any new d.c. stray current interference source is being developed the Promoter of the new system should consult with affected pipeline operators at an early stage and agree the measures to be adopted to manage, assess, mitigate and monitor the d.c. interference risk. This is to ensure the integrity of pipeline systems is not compromised.

In some cases, it may be preferable to relocate the d.c. current source or pipeline to avoid interference effects. Since the stray current interference level decreases with distance, new structures should be located as far as reasonably practical from known stray current sources.

In the case of new tramway developments the Office of Rail Regulator [18], recommends in relation to management of stray current interference “ *It is in the interest of the tramway promoter (this may be the operator or the maintainer) that this will be best achieved by co-operation and information exchange between all of the parties involved leading to agreement.*

Information exchange and co-operation with all potential stakeholders should be carried out during the planning, design and construction stages. This can continue throughout the operation of the system when significant changes to the tramway are planned. In this way, possible effects, suitable precautions and remedies can be assessed.

It is also important that the existence of stray currents from other non-tramway sources, (not restricted to other electric railways), is identified

It is recommended that tramways set up a stray current working party (SCWP) for each project. It is hoped that all statutory undertakers, particularly the utility companies who have any concerns that their apparatus may be affected by stray currents, would wish to be involved and contribute to this working party. The tramway should determine the membership and propose a term of reference /constitution for the SCWP. It would be hoped that this can be agreed by the members on a simple majority basis"

GE/GN8644 [19], provides guidance from the Office of Rail Regulator (ORR) now referred to as the Office of Rail and Road on safety risk management in relation to railway systems.

Promoters and developers of new d.c. power systems should enter into discussions with pipeline operators at an early stage of any new development. This is to discuss and detail the effects any new d.c. power system may have on buried pipelines and how the stray current interference risks can be managed and controlled over the life of the pipeline system.

It is not just d.c. traction systems that may present problems to pipeline operators but other sources of d.c. current can also create issues and a long-term management plan should be considered in such cases. New developments include new HVDC power systems, solar farms or d.c. operated industrial systems.

Liaison should continue throughout the construction and initial operational phase until any identified adverse effects have been identified and resolved and there is a high level of confidence that corrosion damage to buried metallic utilities is unlikely. Thereafter, liaison should continue at a lower intensity throughout the life of the pipeline and transit system.

3.3 Stray Current Forums and Working Parties

It is recommended that stray current interference working parties should not just be created for d.c. traction system developments but stray current interference forums should also be considered for other instances where stray current interference may occur e.g. complex petrochemical sites or pipeline terminals where there are a number of different pipeline operators. Pipelines at terminals are often routed between different plants and can be electrically connected to different pipelines through either earthing systems, a common firewater main or by failure of electrical insulating devices installed on pipelines.

In such sites where there are a number of different pipeline operators and pipeline systems the various pipeline operators should consider convening at regular intervals to discuss the effects of any mutual interaction between different plant CP systems.

Interplant forums can be used to discuss matters of mutual interest between different pipeline and pipework operators in relation to common CP systems and possible stray current interaction. The effect that third-party CP systems can have on adjacent pipelines is an important consideration.

There could be current flow from CP systems on one site to other sites because of common earthing or pipeline systems and that can affect the validity of any CP monitoring or CIP survey data. There may also be stray current interference issues on pipelines or pipework electrically isolated from plant CP systems due to the proximity of adjacent CP systems.

Where modifications to pipe systems or new infrastructure e.g. security fencing are planned on sites where there are different pipeline operators consultation should take place at an early stage to ascertain the effect on buried pipeline systems from d.c. interference or from any planned modifications to an operational facility. The respective pipeline operators should agree likely pre-construction and post construction monitoring and mitigation measures.

CP current flow from adjacent plants or modifications to plant CP systems can affect the CP system on other operators' pipelines. The current flow can result in stray current interference but also mean that true instant OFF pipe to soil potential measurements may not be able to be recorded on certain pipe systems.

This will be due to the fact that current from adjacent CP systems may well flow to other operators pipelines and mean that when site CIP surveys are conducted or routine CP monitoring measurements are conducted that true instant OFF pipe to soil potentials will not be recorded, as not all sources of d.c. current may be switched when a CIP survey or routine ON/OFF monitoring survey is conducted.

The aims and objectives of any forum should be to maintain technical discussions between different Operators for the following purposes:

1) Manage the interfaces between the different Operating Plants.

2) Have technical discussion between the Operators with respect to corrosion related matters affecting each operator and of issues that are of mutual interest.

3) Information exchange between Operators with respect to corrosion control activities and philosophies.

4) Joint activity agreement with respect to common corrosion control measures.

5) Ensure compliance with pipeline industry codes and standards and regulatory compliance.

In the case of pipelines sharing common CP systems the responsibilities for implementing and conducting inspection activities associated with Written Schemes of Examination conducted under the Pressure System Safety Regulations (PSSR) [20],

To achieve full levels of cathodic protection on buried metallic structures.

Manage stray current interference risks between the different CP systems.

Manage the CP systems on various pipelines and ensure effective levels of cathodic protection

Ensure that all pipeline/pipework systems are included in any maintenance strategy

In the case of large terminals or plants there may be a benefit to carry out a joint CIP survey by all operators at agreed intervals, so that all CP system power sources are switched in synchronisation. This would enable true instant OFF pipe to soil potentials to be recorded to identify areas of under protection and locate possible stray current interference locations.

4. PROTECTION CRITERIA AND ASSESSMENT OF STRAY CURRENT INTERFERENCE LEVEL

The criteria for the mitigation of d.c. stray current corrosion on steel pipelines should be based upon the guidance detailed in BS EN ISO 21857 [1].

4.1 Instant OFF Criteria for Protection on Cathodically Protected Steel Pipelines

All pipe to soil potentials should be referred to with respect to a saturated Copper/Copper Sulphate ($Cu/CuSO_4$) reference electrode unless otherwise stated.

Cathodic protection systems must be designed, constructed and operated to achieve the protection criteria specified by the Pipeline Operator. The criteria for effective levels of CP adopted by most pipeline operators are based upon the structure to electrolyte potentials given in Table 1 of BS EN 12954 [8].

In the case of pipelines constructed from mild steel in aerobic soil conditions pipe to soil potentials must be maintained at a more negative polarised instant OFF potential than -0.850V vs $Cu/CuSO_4$.

For buried steel likely to be affected by sulphate reducing bacteria in anaerobic conditions and exposed to an MIC risk, a more negative polarised instant OFF potential of -0.950 V vs $Cu/CuSO_4$ should be maintained.

In cases where the protection criteria detailed in BS EN 12954 cannot be achieved then an alternative ON protection criterion may be considered by a pipeline operator on a case by case basis provided it has been subjected to detailed risk assessment. The 100mV cathodic potential shift criterion is detailed in BS EN 12954 [8] and BS EN ISO 15589-1 [9] and has been based upon the guidance given in NACE Publication Number 35108 [21].

The 100mV potential shift criterion should not be applied to pipelines subjected to d.c. stray current interference.

The maximum instant OFF pipe to soil potentials must be maintained less negative than -1.200V vs $Cu/CuSO_4$ to prevent cathodic disbondment of pipeline coatings In the case of situations where there is stray current interference there may be periods of time when the maximum instant OFF criterion given in this section is exceeded.

4.2 Instant OFF Criteria for Protection on Cathodically Protected CRA Pipelines

Some pipeline operators may use CRA pipelines in specific applications where the product being transported is corrosive, or there could be an internal cracking risk if mild steel was used.

Cathodic protection criteria for CRAs and materials other than mild steel should comply with the values given in Table 1 of BS EN 12954-2019 [8]. The latter standard states that in the case of pipelines constructed from austenitic or ferritic stainless steel with a yield strength less than 800MPa the pipe to soil potentials should be maintained at a more negative polarised instant OFF potential than -0.450V vs $Cu/CuSO_4$ in neutral and alkaline fresh water and soil. No specific guidance on protection potential is given for austenitic or ferritic stainless steels in acidic soil conditions in BS EN 12954-2019 [8].

For ferritic or austenitic stainless steels with a yield strength < 800MPa with a Cr content > 16% the pipe to soil potentials should be maintained at a more negative polarised instant OFF potential than -0.20V vs $Cu/CuSO_4$ in neutral and alkaline fresh water / soil as advised in BS EN 12954-2019 [8].

Operators of CRA pipelines should note that the pipe to soil potentials advised in BS EN 12954-2019 [8] for certain CRAs are different to those previously advised in BS EN 12954-2001 [22], which were that for CRAs with a PREN < 40 the minimum polarised potential criterion should be -0.600V vs $Cu/CuSO_4$ and for CRAs with a PREN >40 the minimum polarised potential should be -0.300V vs $Cu/CuSO_4$.

There is no justification given in BS EN 12954-2019 [8] as to why the reduction in minimum polarised potential criterion has occurred from the previous edition of BS EN 12954 and the author of this GPG's practical experience is that the polarised potential criteria in BS EN 12954-2019 [8] are actually comparable to the natural CRA pipe to soil potentials recorded in practice in the absence of CP.

4.3 ON Potential Criteria for Protection on Cathodically Protected Pipelines

The ON pipe to soil potential that is considered by certain pipeline operators particularly in the UK gas industry as the minimum protection criterion for buried pipelines is a more negative pipe to soil potential than -1.25V vs $Cu/CuSO_4$ measured without interruption of the CP current.

However, there is no actual technical justification for the ON potential value that has been selected and whilst in most cases it is possible to achieve an ON potential value of -1.25V vs $Cu/CuSO_4$ in some cases it may not be possible to achieve an ON pipe to soil potential value of -1.25V vs $Cu/CuSO_4$ such an example would be a sacrificial anode CP scheme on an old coal tar enamel coated pipeline

Thus, wherever possible the instant OFF or polarised pipe to soil potential criteria detailed in Section 5.1 should be used to confirm effective levels of CP on a pipeline system.

BS EN 14505 [23] advises that "An on potential Eon equal to or more negative than –1,2 V, if the measuring point is outside the area of influence of the large foreign cathode (e.g. reinforced concrete or copper earthing system) and if the soil resistivity is sufficiently low (less than about 100 Ω·m) with the exception that an on potential Eon more negative than –0,8 V could be acceptable at entries to, and in the vicinity (within 0,5 m) of large foreign cathodes (demonstrating that the effect of a galvanic cell with the large foreign cathode is mitigated)".

BS EN 14505 [23] applies to complex structures and not pipelines. It is therefore a decision for pipeline operators on what ON potential criterion, if any should apply.

4.4 Maximum Negative Potential Criteria for CP on CRA Pipelines

The maximum pipe to soil potential that should be accepted for pipelines constructed with CRAs or from steel pipelines with a yield stress in excess of 550 MPa should be controlled within set limits as they can be subject to a HISC risk, if there are excessive levels of cathodic polarisation.

There are a number of factors that can affect the maximum permissible negative limit to mitigate any cracking risks e.g. soil pH, soil composition, austenite to ferrite ratio in the case of duplex stainless steels, stress levels and hardness particularly of weldments.

DNV RP F112 [24] gives guidance on the design of components constructed from duplex stainless steels that are installed subsea and are exposed to cathodic protection.

It should be noted that a marine environment may not represent the soil environment in terms of pH and hence the HISC risk.

The guidance in DNV RP F112 [24] is that that duplex stainless steels are susceptible to HISC when exposed to elevated stresses in conjunction with cathodic protection potentials more negative than about -800 mV relative to the Ag/AgCl reference electrode in seawater (-850mV vs $Cu/CuSO_4$). Expert advice should be obtained, and laboratory testing should be carried out to ascertain maximum permissible cathodic polarisation limits on susceptible alloys.

There are various factors that affect the HISC risks on susceptible materials and guidance should be sought to determine the maximum permissible negative structure to electrolyte potential to mitigate any HISC risk.

In soils of pH 8, which is the pH of seawater hydrogen evolution can theoretically occur at potentials more negative than -0.790 V vs $Cu/CuSO_4$ but in acidic soils e.g. pH 5 hydrogen evolution can theoretically occur at potentials more negative than -0.610 V vs $Cu/CuSO_4$. Thus, soil pH will play an important role in determining the risks of HISC on susceptible materials and the maximum potential limit on a pipeline constructed from certain CRAs. It should be noted that the maximum permissible negative potential on susceptible materials is typically more negative than the values at which hydrogen evolution can theoretically occur

4.5 Stray Current Interference Criteria

The criteria applicable to pipelines subjected to stray current interference depend upon whether the pipeline system or structure under consideration has or does not have a cathodic protection system applied.

A structure that is affected by stray current interference but does not have CP applied would be for example a steel water pipeline/main, electrical metallic sheathed cable or rail line. A structure with cathodic protection applied would be a gas, oil, water or product pipeline.

4.5.1 Structures without Cathodic Protection

In the case of a steel structure that is not cathodically protected the maximum anodic potential shift that will be permitted on an affected structure is +20mV in soils of resistivity less than 15 Ohm m.

This is taken as the potential difference between the structure to electrolyte potential when the third-party CP system is off and when the CP system is on.

An anodic potential shift of less than +20mV is acceptable. If the anodic potential shift exceeds +20mV then the structure will be deemed to be suffering stray current interference at an unacceptable level.

Thus, if the third party structure to soil potential was – 0.520V vs $Cu/CuSO_4$ with a pipeline CP system on and – 0.550V vs $Cu/CuSO_4$ with a pipeline CP system off, then a positive potential shift of +30mV would be recorded and the third party structure would be at risk of corrosion, if the soil resistivity was less than 15 Ohm m.

BS EN ISO 21857 [1] relates the maximum permissible potential shift ΔU as shown on Table 4. The maximum potential shift permitted is dependent upon the soil resistivity in which the pipeline or structure is installed.

Thus, in high resistivity soils a potential shift in excess of +20mV can be accepted based upon the guidance in Table 4.

Component	Resistivity ρ of Electrolyte (Ohm m)	Maximum positive potential shift ΔU (mV) (including IR-drop)	Maximum positive potential shift ΔU (mV) (excluding IR-drop)
Steel	>200	300	20
	15 to 200	1.5 ρ	20
	< 15	20	20

Table 3 Relationship between soil resistivity and permissible anodic shift on non cathodically protected structure (BS EN 50126)

A negative potential shift in excess of 20mV will not be detrimental unless it results in a pipe to soil potential at which cathodic disbondment can occur, as the structure will be receiving current at that location where the measurement is made and will be either partially or fully cathodically protected.

However, a negative shift does indicate that current is entering the structure and where current enters at one point it must leave at others.

The locations at which current leaves a pipeline should be identified to ensure the potential shift is less than +20mV. In accordance with the guidance given on Table 3 higher positive potential shifts can be accepted on non cathodically protected pipelines for soil resistivities above 15 Ohm m.

To determine the permissible potential shift in mV in soils of resistivity between 15 to 200 Ohm m the soil resistivity ρ in Ohm m should be multiplied by 1.5.In the case of d.c. stray current interference, the third-party structure owner should be consulted on the maximum permissible potential shift that will be accepted.

In the case of pipelines crossing railway lines stray current interaction tests should be offered to the Railway Authority. Railway authorities are interested in stray current interaction tests for two reasons the first reason is to determine if the rail lines have an enhanced risk of corrosion from any third party CP system but the second reason is to determine if a pipeline CP system has any effect on the rail signalling.

4.5.2 Structures with Cathodic Protection

In the case of a pipeline that is cathodically protected the maximum anodic potential shift that can be permitted on an affected pipeline should be such as to ensure that a cathodically protected potential is still achieved on the structure that is being interfered with.

Interference by stray currents shall be deemed to be unacceptably high if the interference causes the IR free potential to be less negative than the limiting IR-free potential (see BS EN 12954). This means that the IR free protection potential should not be less negative than the pipeline operators specified minimum instant OFF potential criterion for the pipeline system under consideration

Negative potential shifts due to cathodic interference on a certain part of a structure (usually) implies that there are other parts, which are subject to anodic interference.

If very negative potential shifts (e.g. ΔV > 500 mV, IR-drop included) are measured, it is recommended that steps are taken to identify areas where anodic potential shifts occur to confirm compliance with the minimum protection criteria given in BS EN 12954 [8].

This will mean surveying the affected pipeline to establish locations where anodic potential shifts occur.

A CIP survey will be the most effective method of establishing stray current discharge locations with the third-party pipeline CP system switching.

A negative shift as a result of stray current interference should not exceed the limits defined in Section 5.1

Potential values recorded during the non-operational period of an interfering system should be considered as the normal or unaffected potentials. Thus, in the case of pipelines affected by stray current interference from rail traction systems this will generally be at night-time (see Section 5.8).

However, it is essential to ascertain the pipe to soil potential of the structure being interfered with. when the interference is occurring, as that will be the situation where there is the highest risk of damage due to stray current and that the pipeline system is generally exposed to during its' normal operation. Carrying out over the line surveys or routine monitoring at night-time will not fully replicate the situation in normal operation but will establish the base line potential and coating anomalies. Structures protected against corrosion by cathodic protection shall be deemed to be exposed to unacceptable levels of stray current interference if the IR free potential is outside the protective potential criteria given in BS EN 12954 [8].

To evaluate the acceptability of stray current interference the installation of test probes and coupons should be considered. In the case of stray current interference, it is not always possible to measure a true IR free potential, as not all current sources affecting a pipeline can be interrupted during a CP survey. In situations with fluctuating interference then current probe or coupon measurements where the direction and magnitude of current flow on and off a coupon/probe can be measured should be used to evaluate the acceptability of the levels of interference. The measurement circuit should also preferably include a means of measuring the coupon instant OFF potential at periodic intervals. Measurement of coupon instant OFF potentials is one means whereby it can be established if during periods of stray current interference that acceptable polarised potentials are achieved.

The impact of short-term anodic peaks, soil resistivity/aerobic/anaerobic variations over the year, etc. is not clear. If in special situations (e.g. under d.c. traction influence) where there are reasons to doubt the accuracy of the measurement method used then other measurement techniques should be employed e.g. the use of weight loss coupons, excavation and laboratory examination of coupons used for routine monitoring or the use of electrical resistance (ER) probes. The ER probes used may be either capable of manual or remote access measurement. ER probes can be used to establish whether the structure is cathodically protected or if it does not have effective levels of CP what the likely rate of corrosion will be. Appendix G of this GPG provides guidance and further information on corrosion rate measurement techniques.

Measurements should be carried out during a period of normal operation of the interfering system. Ensuring that the ON potential for the affected pipeline remains more negative than -1.20V vs $Cu/CuSO_4$ would assist in ensuring effective levels of CP if the instant OFF potential cannot be measured.

BS EN 50162 [2] advised that the relationship between the anodic d.c. current density J and potential shift ΔV indicated on Table 4 is determined by equation 4).

$$J = \frac{8\Delta V}{\pi \rho d} \qquad 4)$$

Where J = Anodic current density (Am^{-2})
ΔV = Potential shift (mV)

ρ = Soil resistivity (Ohm m)
d = Coating defect diameter (m)

4.6 Assessment of Stray Current on Pipelines

The method of assessment of d.c. stray current levels should be based upon guidance given in BS EN ISO 21857 [1].

Step 1 **The probe or coupon current corresponding to the cathodic protection potential of the pipeline (based upon the guidance given in BS EN 12954) should be measured during a period when the pipeline is not interfered with by fluctuating stray current (e.g. at night). This probe current is defined as the 100 % (reference value) as shown in Figure 5 period 'A').**

Step 2 The probe or coupon current (the resultant of cathodic protection current and stray current) is continuously recorded during a period of typically 24 hours.

Step 3 For evaluation the hour with the highest probe current reductions (i.e. the hour with the most positive potential fluctuations) is identified (period 'B' in Figure 5).

Step 4 Probe currents below any of the values given in column 1 of Table 4 indicate a high risk of corrosion if their accumulated duration exceeds the corresponding values of column 3 of Table 4.

The d.c. corrosion rate can be associated with the period of time that the current density on the coupon is less than the reference level. The reference level is the current density that flows to the coupon when there is no interference. If there is interference, then the level of cathodic current density can decrease and so will the pipe to soil potential. The worst case is when the current rather than enter a coupon actually leaves and there is anodic discharge during that period of time then accelerated corrosion or metal loss can occur.

The use of coupons is essential in monitoring the levels of d.c. stray current interference, as it can enable not just ON and instant OFF potentials to be recorded but also enable the current flow to and off a coupon to be measured to assess the stray current interference risk.

Figure 4 shows how the d.c. current density flowing onto or off a coupon can be measured.

Figure 5 shows the relationship between d.c. current density at the reference level i.e. when there is no d.c. stray current interference and the d.c. current density when there is stray current interference.

Figure 6 in this GPG shows the relationship between the risk of corrosion on pipelines based upon the period of time that the d.c. current density is at a set percentage of the reference level or d.c. current density, when there is no d.c. stray current interference and has been based upon the guidance given in BS EN ISO 21857 [1].

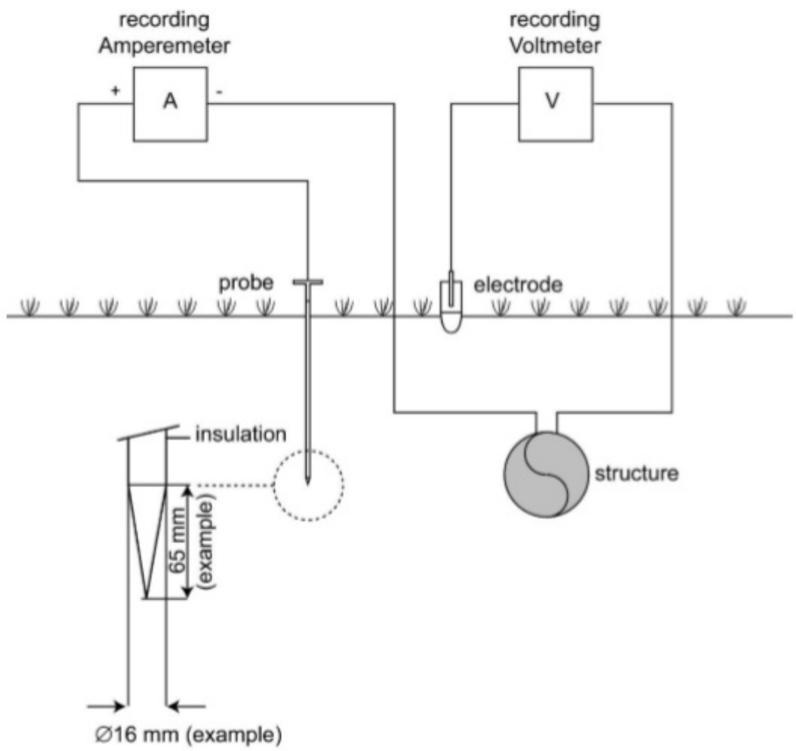

Figure 4 D.C. current flow off coupons and measurement technique. Ideally 1cm^2 exposed surface area coupons should be used. Graph extracted from BS EN ISO 21857

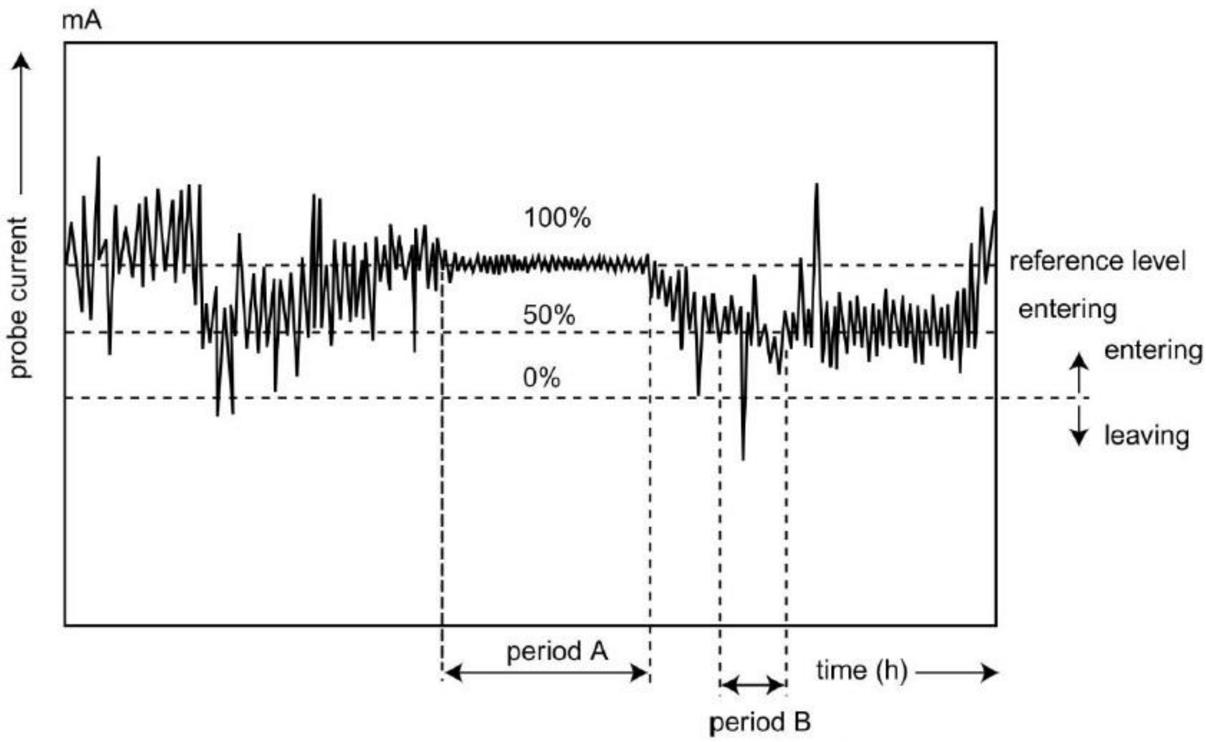

Figure 5 D.C. current flow off coupons and assessment of corrosion rate.

Probe current in % of the reference level	Maximum acceptable occurrence period	
	in % of the worst hour	in seconds
> 70	Unlimited	
< 70	40	1 440
< 60	20	720
< 50	10	360
< 40	5	180
< 30	2	72
< 20	1	36
< 10	0.5	18
< 0	0.1	3.6

Table 4. Relationship between acceptable periods of time that current levels off a coupon are below an acceptable level and corrosion likelihood extracted from BS EN ISO 21857.

In some cases, pipeline operators can with the aid of coupons and suitable data loggers record the period of time that the coupon IR free or instant OFF potential is less than the pipeline operator's minimum instant OFF potential and use that data to assess the level of risk to a pipeline system.

However, to perform coupon instant OFF potential measurements a data logger that is capable of switching a coupon would need to be employed. The coupon switching cycle should be in a ratio of 4 periods of time ON and 1 period of time OFF to prevent depolarisation of the coupon

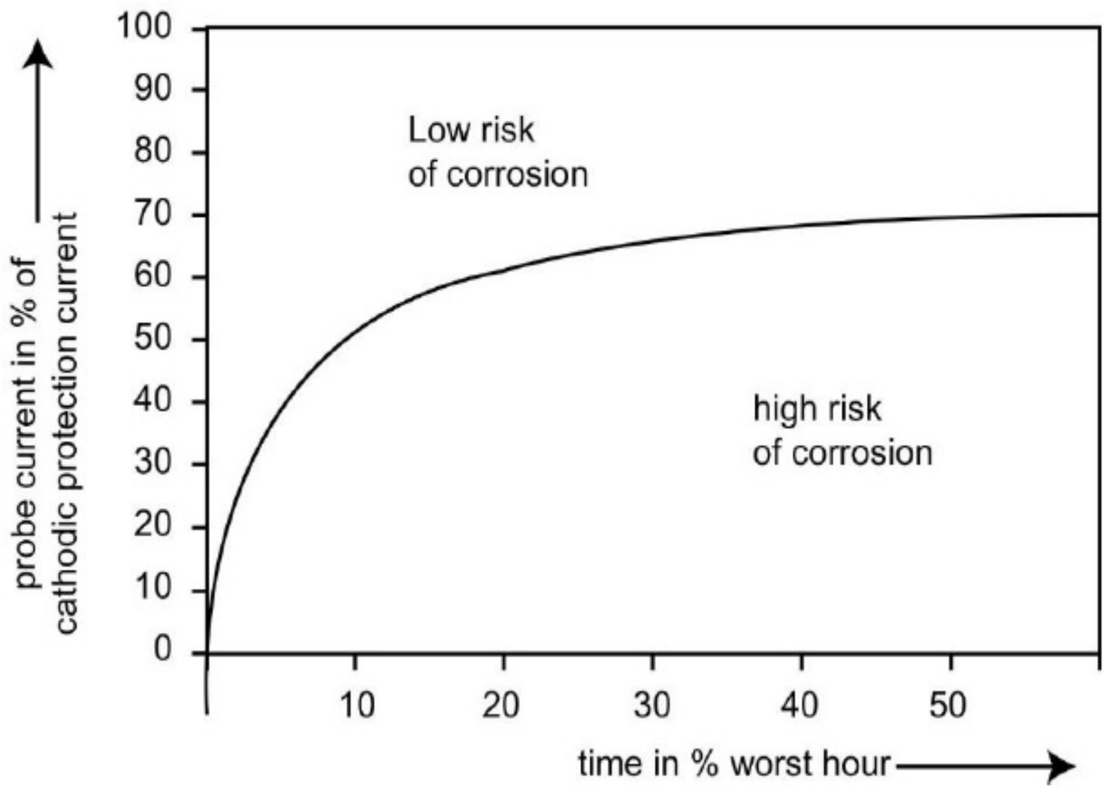

Figure 6 Period of time current is less than reference level and acceptable value.

Note 1: *Whilst it can be said that only anodic (positive) reactions lead to corrosion damage, it is important to also consider cathodic (negative) reactions, as a cathodic shift (usually) implies that anodic reactions are taking place elsewhere on the structure.*

Note 2: *Measurement of energised CP potentials includes a measurement error known as IR error. Error free potential measurements known as polarised potentials are normally measured with the CP current being switched "ON" and "OFF." However, in the case of D.C. transit systems, it is clearly impossible to switch off the interference current to obtain error free potentials. Therefore, to enable the acceptability of stray current interference to be assessed, additional test facilities such as permanent reference electrodes and coupons should be considered, and measurements should be taken during a period of normal operation of the interfering system.*

Coupons are required at critical locations to accurately assess the risk of corrosion where there is d.c. stray current interference.

Data loggers should be employed with capability to mathematically analyse the data obtained, preferably by providing data in an Excel format so that accurate values for the periods of time that the coupons do not achieve the required current density and potential can be established.

Coupons are essential for establishing the levels of d.c. stray current interference on a pipeline susceptible to stray current interference and to assess the stray current corrosion risk.

4.7 Stray Current Monitoring Measurements in Practice

CP test facilities on pipelines affected by stray current interference should ideally contain a 1 cm^2 coupon and a suitable permanent buried reference electrode. A cable connection to the pipeline is also required of a minimum conductor size $10mm^2$. The pipe cable colour should conform to the pipeline operators' specific colour requirements for identification of pipe connections.

Where bonds are employed or are located at drain points then there should be a separate current carrying cable and potential measurement cable. The potential measurement cable should not be used to carry current.

Suitable designation in terms of either cable colour or the use of cable markers should be provided to indicate whether any coupon has a $1cm^2$ or 10 cm^2 exposed surface area coupon.

The preferred coupon surface area for monitoring d.c. stray current interference levels is 1 cm^2 but in situations where there is only a d.c. polarisation coupon typically of $10cm^2$ surface area or in some cases $25cm^2$ surface area then the latter coupon geometry can still be used to determine d.c. current density but the values obtained should be treated with caution.

The magnitude of the coupon current density can be used to assess the corrosion risk on a pipeline system together with information on the period of time that any anodic current discharge occurs for. A data logger is required to monitor the time dependent variation of d.c. current density to provide information on the levels of interference.

Figure 7 shows a typical plot for d.c. current discharge through a coupon on a pipeline affected by d.c. stray current interference.

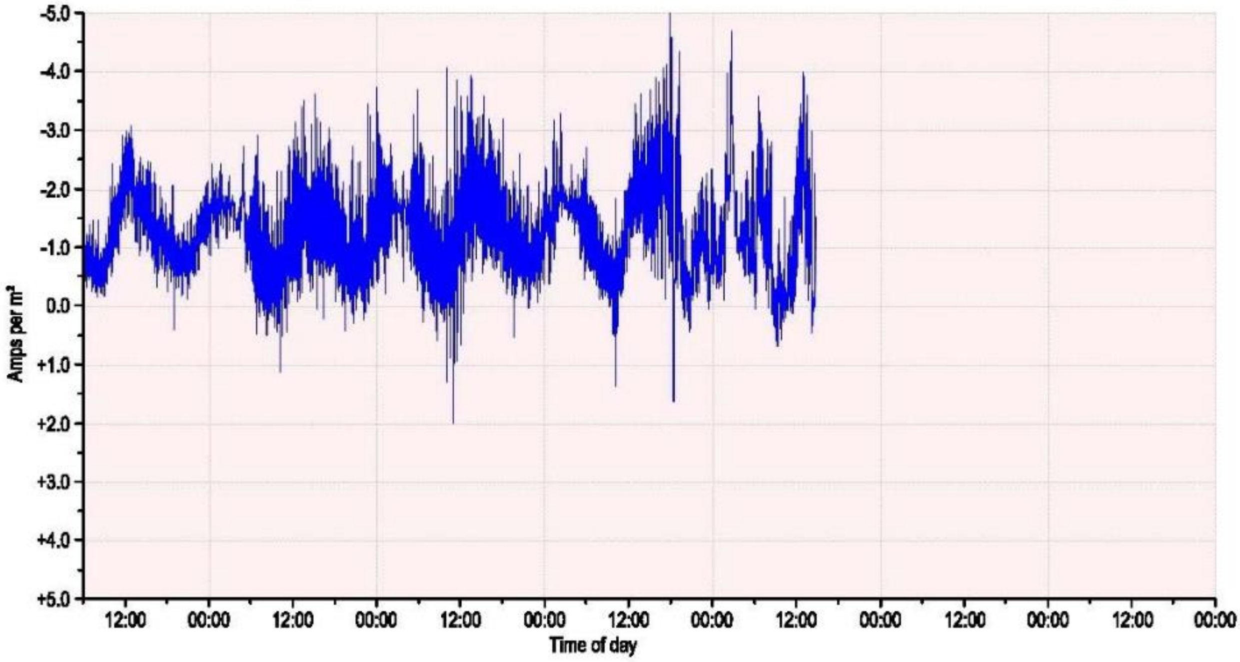

Figure 7 D.C. current density flow off coupon negative values are periods of time coupon under CP THE positive current discharge occurred during anodic potential shifts

The positive current density is the nett period of time the current density discharge through the coupon was anodic i.e. current was discharging off a coupon rather than entering the coupon. The negative current density flow is the cathodic current density to a coupon. The corrosion rate is associated with the number of coulombs (Q_A) that have flowed in the anodic direction.

In the case shown in Figure 7 if an anodic current density of 1 Am^{-2} occurred over a 24-hour period then the corrosion rate would be 1.1mm yr^{-1}. Thus, the metal loss over a 24-hour period would be 0.003mm if all the current was in an anodic direction and uniform corrosion occurred.

However, in the case of the current density plot shown in Figure 7 as an anodic current only occurred for less 1% of the time over a 24 hour period and the average anodic current density was less than 1 Am^{-2} then the annualised corrosion rate on the coupon determined from equation 5) would be approximately 0.011mm yr^{-1} and not a significant risk.

An assessment of the periods of time that an anodic current density was recorded can be used to indicate level of corrosion risk on pipelines affected by stray current.

It should however be noted that such an assessment of corrosion rate would only be an approximation as not all the anodic current density may be associated with the iron dissolution reaction.

The relationship between the anodic current density over a 24-hour period and the likely corrosion rate K_{corr} can be given by equation 5 and is based upon Faraday's Law

$$K_{corr} = \frac{I_A x\ T\ x 1.1}{86{,}400} \qquad 5)$$

Where	K_{corr}	=	Corrosion Rate mm yr^{-1}
	I_A	=	Average anodic current density over a 24-hr period (Am^{-2})
	T	=	Total period of time anodic current density was observed over a 24-hour period (seconds)
	86,400	=	Number of seconds in a day

It should be noted that equation 5) is just an approximation and only provides an indication of the likely corrosion rate on pipelines affected by stray current interference.

4.8 Time Variant d.c. Interference

BS EN ISO 21857 [1] provides guidance on assessing the time dependent variation in d.c. stray current interference on pipelines due to d.c. operated railways, telluric currents and tidal effects. Reference to BS EN ISO 21587 should be made to provide detailed guidance on the assessment of time dependent variation of d.c. interference.

Also, advising that the time (t) variations of interference levels e.g. Eon(t), is considered to consist of successive intervals with anodic, Ea(t), and cathodic, Ec(t), polarization.

BS EN ISO 21857 [1] states that the words “anodic” and “cathodic” are defined with respect to a selected reference potential level E_{Ref} i.e. the pipe to soil potential during periods when there is no or limited stray current interference (see Figure 8).

The interference level should be monitored over a representative duration typically 24 hours. The reference potential E_{Ref} is evaluated from the interval when the interfering source is out of operation, e.g. during the night in the case of d.c. traction systems.

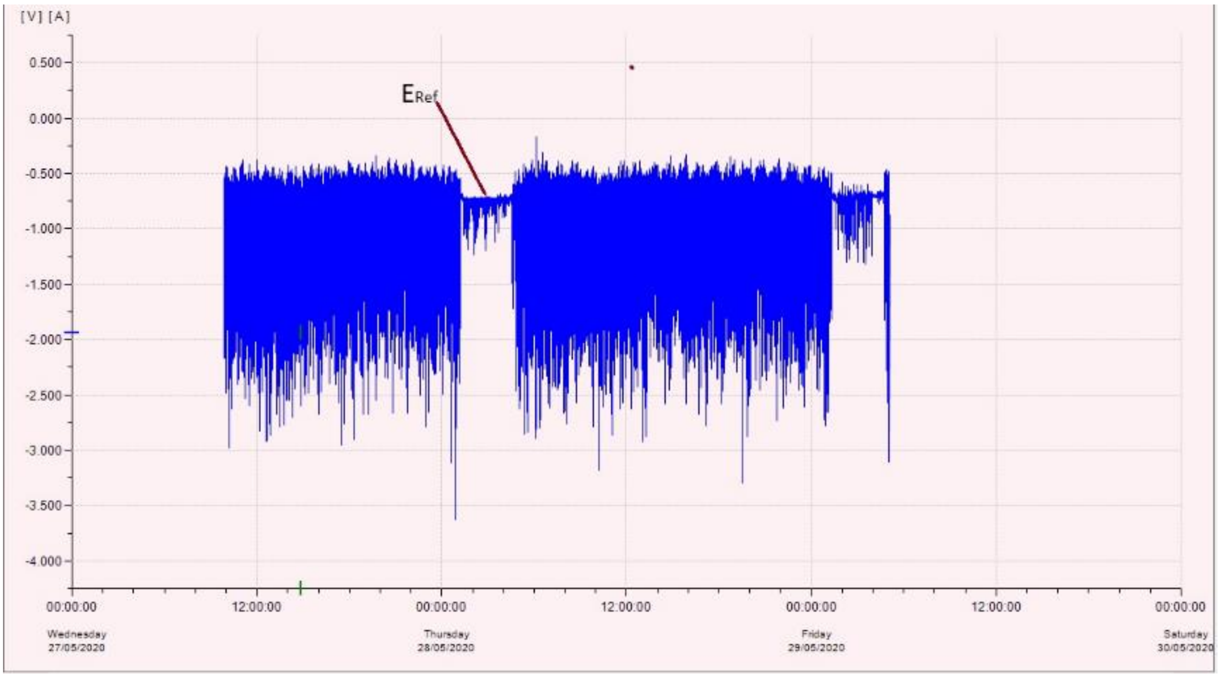

Figure 8 E_{Ref} on a pipeline susceptible to d.c. stray current interference when the stray current from the interfering source e.g. d.c. traction system is off or at a reduced level.

Intervals of anodic interference are identified from Ea(t) = E(t) - Eref >0. 3) where E(t) is the measured potential at a given time.

Intervals of cathodic interference are identified from Ec(t) = E(t) - Eref < 0. 4) where E(t) is the measured potential at a given time

The average anodic interference, ΔEa, avg, is assessed from a representative measurement of Eon(t) showing intervals when the interfering source is in and out of operation.

To determine the Ea avg the values of Ea(t) over the total time period of monitoring typically 24 hours should be determined, with all negative values replaced by a zero and to determine the Ec avg the values of Ec(t) over the total time period of monitoring typically 24 hours is determined, with all positive values replaced by a zero

Anodic interference would be deemed acceptable if ΔEa, avg is within the limits defined for ΔEa in Sections 5.1 or 5.2. BS EN ISO 21857 [1] advises different methods that can be used to determine whether the time variant interference is acceptable: Time variant interference will be deemed acceptable if the IR-free potential of the structure, $E_{IR\ free}$ (E_{OFF}) is within the limits for the protection potential, Ep, given by BS EN 12954. The IR-free potential can be measured with the use of coupons and data logging devices specifically designed for monitoring d.c. stray current.

The reference ON-potential Eref, at which effective CP in accordance with BS EN 12954 [8] is just achieved is determined during the period without interference (e.g. during the night in the absence of train operation). Subsequently the average anodic potential shift ΔEa, avg should be determined over a representative period of time, typically 24 hours, with the CP system in continuous operation (no switching of the transformer rectifiers).

A sufficient level of cathodic protection is ensured, if equation 6) is satisfied:

Eon, avg ≤Eref - ΔEa, avg 6)

This methodology is based on the assessment of traction system interference where the maximum time interval (Ta, max) of anodic excursion does not exceed 250 s. BS EN ISO 21857 states that *the value of Ta, max = 250s is a conservative value derived from field measurements of typical d.c. traction interference.*

The Q method is described in BS EN ISO 21857 [1], which uses the ratio between the anodic and cathodic charge to determine if the level of interference is acceptable.

The anodic and cathodic potential shifts although not given as units of charge i.e. Coulombs are considered to be proportional to charge BS EN ISO 21857 [1] states.

$$Q = \frac{(Qc - Qa)}{Qa} \qquad 7)$$

Where Q= Charge ratio
Qc= Nett cathodic charge
Qa = Nett anodic charge

Interference is considered to be within acceptable limits if Q is ≥ 0.004 s^{-1} x Ta max

For worked examples using the Q factor and assessing the time dependent variation in stray current interference reference should be made to BS EN ISO 21857 [1].

BS EN ISO 21857 [1] states that Q is equivalent to.

$$Q = \frac{\left(E_{ref} - E_{ON\ AVG}\right)}{\Delta E_{a\ avg}} \qquad 8)$$

Where Q = Charge ratio
E_{REF} = Reference ON potential when there is least interference
$E_{ON\ avg}$ = Average ON potential
$E_{a\ avg}$ = Nett anodic charge i.e. Ea avg

The total charge Q is related or proportional to the pipe to soil potential.

Interference is considered to be within acceptable limits if Q is ≥ 0.004 s^{-1} x Ta max

For worked examples to calculate the Q factor and assessing the time dependent variation in stray current interference reference should be made to the informative Annex in BS EN ISO 21857 [1].

It should be noted that the Q factor method based upon practical assessments has its limitations and may not always provide effective confirmation of interference levels in all situations.

5. DC STRAY CURRENT SOURCES

5.1 General

There are various sources of d.c. stray current interference that can affect buried pipeline systems and these are identified in this section.

The subject of stray current interference from d.c. traction systems is discussed in greater detail in Appendix C of this GPG. Further guidance on the effects of d.c. stray current interference from different sources is given in different sections of this GPG.

5.2 London Underground Traction Circuits

The London Underground traction system is termed a fourth rail d.c. power system. There are two running rails used for the railway carriages, which do not carry current and two used for the d.c. power circuits. London Underground fourth rail systems have historically resulted in limited levels of d.c. stray current interference on buried pipelines.

5.3 D.C Light Railway /Tramway Circuits

Light Railway and tramway systems use a third rail system. A third rail is a method of providing electrical power to a railway system, through a continuous rigid conductor placed alongside or between the rails of a railway track or on an overhead conductor. The running rails carry the d.c. traction return current that with the London Underground is carried by the fourth rail.

There are nine tramway/light rail systems in the UK at the time this GPG was written; namely Birmingham, Blackpool, Croydon, Edinburgh, London's docklands (DLR), Manchester, Newcastle upon Tyne, Nottingham and Sheffield. The third rail may run alongside the train system as is the case with the DLR or over overhead as is the case with the Croydon Metro. The Edinburgh tram system operates at 750V d.c., the Tyne Metro 1500V d.c. and the Croydon and Manchester Metro 750V d.c.

5.4 D.C. Traction Systems

D.C. third rail traction system operator running rails are not effectively insulated from earth and significant levels of d.c. current can flow in the general mass of earth from the rail system. The older rail lines operate at 660V and the newer lines operate at 750V.d.c. D.C. traction systems have an insulated positive conductor or outer rail and they use the traction system running rails to carry the d.c. negative return current to the d.c. power source.

5.5 D.C. Welding Operations

D.C. welding operations during pipeline construction and repair can cause stray current interference and corrosion on metallic structures if not carried out correctly (see Section 9.3).

5.6 Third-party CP Systems

Where pipelines are routed in close proximity to or cross other cathodically protected pipelines. There is a risk of stray current interference from the third-party pipeline CP system on an operator’s pipeline.

The level of stray current interference is dependent upon the separation distance between an operator’s pipeline and any third-party pipeline groundbed and the operating current and voltage of the third-party pipeline groundbed or groundbeds.

Appendix D provides additional information on the interaction effects from third party CP systems and requirements for testing. It has been based upon the guidance previously given in the now withdrawn standard BS 7361 Part 1 [25].

5.7 Solar Farms

Solar farms or Photo-Voltaic (PV) farms can produce stray d.c. current during normal operation and fault conditions. The electrical details of the solar farm installation should be established with the Promoter of any new solar farm.

UKOPA has given guidance on siting of solar farms in close proximity to buried pipelines in its Good Practice Guide UKOPA/GPG/014 [3].and the latter document should be consulted in relation to solar farms.

Solar farms should be located as far as possible from buried pipelines to minimise the d.c. stray current risks.

5.8 Incorrect Polarity of CP systems

CP transformer/rectifier (T/R) units can be wired up incorrectly i.e. the pipe d.c. negative terminal on the d.c. output could be connected to a groundbed and the d.c. positive groundbed terminal connection to a pipeline. This may happen where electrical personnel may not be aware of the risks associated with enhanced corrosion on a pipeline by incorrect polarity of connection on d.c. power sources, where the same cable colour is used for the pipe and groundbed connection cable, the pipeline is inadvertently connected to the positive output terminal of a CP T/R unit or repairs are carried out to a CP transformer rectifier.

If such a situation happens i.e. incorrect connections are made within a T/R unit then accelerated corrosion on a pipeline can occur and lead to failure of a pipeline system or result in significant levels of damage in a relatively short period of time.

5.9 HVDC Power Systems

HVDC transmission systems can cause stray current interference on buried metallic structures. It is known that problems have been experienced on pipeline systems in other countries from HVDC power transmission systems. D.C. current leakage from a HVDC substation earth can occur during normal operating conditions, when there are changes in the operational configuration of the HVDC system or during faults on the HVDC system and these conditions can result in d.c. interference.

Overhead HVDC cable transmission systems cause higher levels of interference than buried HVDC cable systems because the overhead aerial earth wire will bond all the HVDC pylons together.

5.10 Telluric Interference

It has been known for a number of years that geomagnetic field variations associated with ionospheric currents or solar sunspot activity can establish large scale electrical currents in the earth's crust by a process of electromagnetic induction.

The pattern of this current flow can be quite complex due to the relatively wide variation in the electrical conductivities of the different materials within the Earth's crust and the high contrast in conductivity between the land and sea.

The stray currents in the earth caused by geomagnetic variations are termed “telluric currents” and they are said to be common between the regions close to the North and South Poles.

D.H. Boteler and L. Trichtchenko [40] give detailed guidance on Telluric interference and the latter publication should be consulted for additional information on the subject, as should BS EN ISO 21857 [1].

It should be noted that in the UK whilst telluric interference has been reported on some pipeline systems it has not been considered to pose a significant effect on the integrity of the UK pipeline network.

5.11 D.C. Operated UPS and Instrumentation Systems

D.C operated UPS and instrumentation systems can cause periodic stay current interference on pipelines especially if positive grounding is employed. Such interference would be exhibited by short duration pules in pipe to soil potential evident on routine monitoring surveys. The interference can occur where there are grounding electrodes located close to a pipeline on +48V positive grounding instrument circuits. This type of interference is generally not detrimental to a pipeline system integrity due to the low current levels.

5.12 Battery Energy Storage Sites (BESS)

In recent years some power stations are planning to install battery storage so that energy from offshore wind farms can be stored during low power demand periods and to provide extra power to stabilise the electrical supply voltage on the National Grid or to provide short term up to 4 hours power capacity. These sites can consist of a large number of batteries with some newer sites planned to have the ability to provide in the region of 300MW of power.

In the event of a d.c. current fault to ground significant current levels can flow and there would be the potential to cause damage to buried metallic utilities nearby as a result of a short-term interference event.

5.13 D.C. Operated Industrial Systems

D.C operated industrial electrical systems can cause stay current interference on pipelines, if current leakage occurs e.g. factory operated power systems that use or generate d.c.

5.14 Tidal Interference

BS EN ISO 21857 [1] has identified that there can be stray current interference due the flow of conductive seawater through the earth’s magnetic field. This type of interference is described in detail in BS EN ISO 21857 [1] but has not as far as the author of this GPG is aware has not been reported on onshore pipelines in the UK.

5.15 A.C Interference on Pipelines and A.C Interference Mitigation Systems

Where a.c. interference is present on a pipeline the a.c interference can create fluctuating levels of d.c. potential on a pipeline. This can occur because the a.c. voltage present on a pipeline may be present across the d.c. output terminals of a transformer rectifier and could be rectified by the transformer-rectifier. Pipeline operators should be aware of this possibility as the CP transformer rectifiers dependent upon their method of control may rectify the a.c. voltage present on a pipeline at a CP station and produce a fluctuating d.c. current output.

6. STRAY CURRENT INTERFERENCE ISSUES FOR PIPELINES

6.1 General

The design of any or new or diverted pipeline system should include an assessment of the risk of d.c. stray current interference. This should include identification of possible d.c. interference sources along a pipeline route, location and details of third-party pipelines and their CP systems, risks of d.c. interference during construction and also during pipeline operation.

The design should also include an assessment of the levels of d.c. stray current interference that may already be present on existing pipeline systems and if the interference could be detrimental to any new pipeline or diverted pipeline section.

Wherever possible planning for new pipelines should avoid routes having long parallelisms with d.c. transit systems, crossings of d.c. traction circuits and/or be routed in close proximity with d.c. traction system sub-stations. Where parallelism of d.c. traction systems and pipelines are unavoidable, consideration should be given to electrical isolation of pipeline sections parallel to the d.c. traction return rails using factory-built I/Js. Crossings of d.c. operated traction systems or running parallel with d.c. traction systems should be avoided where possible.

The use of I/Js can provide electrically discrete pipe sections to mitigate the stray current interference risk and create localised manageable sections of stray current interference. I/Js may need to be considered at the design stage for new pipeline systems to ensure that the d.c. stray current interference effects are limited. On lower pressure gas systems considerations should be given to replacing metallic sections with HDPE sections at rail traction crossings.

Similarly, in the case of PV farms pipelines where possible should be routed as far as possible from existing PV farms with a separation distance of preferably 100m to ensure that a PV farm is at remote earth in relation to the pipeline.

If modifications or diversions to existing pipeline systems are planned, then the CP status of the existing structure should be determined. It should be ascertained if any existing pipeline system to which a new or diverted pipeline will be connected already suffers from d.c. stray current interference. In the case of pipeline diversions or modifications differences in coating quality between existing and new pipe sections can affect the levels of interference that may be experienced. Newer pipeline coatings e.g. FBE and 3-layer polyethylene have a higher coating resistance (impedance) than the older coal tar enamel coatings and will be more susceptible to the effects of d.c. stray current.

6.2 Pipeline Route Selection

Pipeline routes should be selected so as to avoid third party pipeline groundbeds and other sources of d.c. interference e.g. d.c. traction systems, solar farms, battery storage sites, industrial d.c. power systems or HVDC power systems.

The guidance given in HSG 47 should be followed in relation to buried services and where appropriate searches should be undertaken to identify buried utility operators along a proposed pipeline route.

A new pipeline should ideally be located at least 400m away from any third party groundbed. It may be possible to install pipelines closer than the 400m separation distance but in such a situation the possible effects on the pipeline from any third party groundbed would need to be considered and detailed guidance sought.

Guidance on calculation methods to determine d.c. interference levels and whether a groundbed will be at remote earth from a pipeline at a given location is provided in Section 6.11 of this GPG.

The higher the third party groundbed operating current the greater the separation distance that is required between the interred pipeline and the third-party pipeline.

If a new pipeline crosses existing third-party pipelines it is important to establish with the third-party pipeline owner, whether the pipeline has a CP system or not, plus the location and attributes of any existing pipeline CP test facilities and the location of all CP groundbeds on the third party pipeline or pipelines.

The requirements for stray current interaction testing should be agreed with the third-party pipeline operator together with the requirements for CP monitoring facilities during the detailed design phase of any new or diverted pipeline. Additional guidance on this topic is provided in Appendix E

It is essential that the locations of all groundbeds on any third party pipeline are identified and the operating current outputs established, In the case of pipelines routed through plant areas the area of influence of any groundbeds within a plant e.g. above ground installation (AGI) or terminal should also be considered.

In certain instances, if it is not possible to avoid the close proximity between a pipeline and a third party groundbed then it may be necessary to relocate the third party groundbed to limit the stray current interference risk. If groundbed relocation is required, then this may take time to arrange. Due consideration should be given to the likely time scale required to relocate groundbeds at the commencement of the pipeline design.

Relocation of groundbeds can be expensive as new land rights may need to be obtained, planning permission sought for the new CP T/R location, new drain point connections may need to be installed and a new a.c. supply arranged.

Inter-pipeline bonds can also be used to combat any d.c. interference between respective pipelines but should be avoided where possible and if not possible to avoid they should only be installed with both pipeline operator’s agreement. They would also need to be effectively managed and monitored in future and at least two bonds installed to provide an element of system redundancy.

6.3 Mitigation of Stray Current

Several options are available for the reduction or elimination of d.c. interference between two or more cathodically protected pipelines and the various options should be considered during the design phase of any pipeline system or any review stray current effects on existing pipelines. The effectiveness of these measures depends upon the extent of interference, co-operation between the concerned pipeline owners and site conditions.

6.3.1 Adjustment of the T/R unit output

The interfering pipeline’s T/R unit or units’ current output can be reduced to the minimum level required to provide cathodic protection. If the minimum level is already achieved, then consideration may be given to the installation of additional T/R units and groundbeds along the pipeline route. This will result in the reduction in the current output from individual T/R units and associated levels of interference.

A number of smaller current output CP T/R units and groundbeds may be used as part of the pipeline CP system design process to reduce the stray current interference levels on third party pipelines. This would decrease the current output per CP station and reduce localised stray current interference effects.

6.3.2 Groundbed location of Interfering Pipeline

If the 'interfered with' pipeline is subjected to the voltage gradient of the groundbed of an interfering pipeline e.g. where pipelines are routed in a common right of way but not electrically connected, increasing the separation distance between the pipeline (Interfered with) and the interfering groundbed is a possible solution. Section 6.11 provides details of the calculation methodology to determine whether a groundbed is at remote earth in relation to a pipeline.

The distance increase can be obtained in either the horizontal or vertical direction. Increase in horizontal separation is often the preferred and least expensive option.

In situations where pipelines are routed in a common right of way and the pipelines are owned by different operators or even owned by the same pipeline operator. If a pipeline groundbed is not at remote earth, then its voltage gradient can interfere with other pipelines if the pipelines are not bonded.

Increase in the number of CP stations and thereby reducing the current requirement from each groundbed can also be a means of reducing the interference levels.

The soil resistivity and groundbed operating current affect the separation distance required to achieve remote earth. Specialist advice should be obtained to confirm the minimum separation distance between groundbed, and pipeline required to ensure a groundbed is at remote earth.

A typical separation distance between a pipeline and groundbed would be in the region of 120m to 200m to ensure that a groundbed is at remote earth see Section 6.11 [9] of this GPG. However, if the groundbed operating current is high >5 Amps the separation distance may need to be greater than 200m.

6.3.3 Unidirectional and Forced Drainage Bond

A unidirectional bond between d.c. traction systems and the interfered with pipeline with a resistor and diode can drain the stray current away from the interfered pipeline to a d.c. traction system return conductor. The design of the bond will need to be agreed with both the pipeline operator and rail operator or the operator of the pipeline system to which any bond is connected.

Guidance on the design of uni-directional bonds and forced drainage bonds is given in Appendix C of this GPG.

The bond should include a fuse to limit the current flow and provide circuit protection, two diodes should be provided in the unidirectional bond to ensure that in the event of closed-circuit failure of one diode the remaining diode still operates effectively and current will flow in only one direction. If a diode fails it can mean that the pipeline may be directly connected to the traction circuit and as a result could

Where existing bonds are installed and there is only one diode in the bond consideration should be given to the addition of another suitably rated diode to mitigate the risk of direct connection of the pipeline to the traction circuit in the event of diode failure should be considered.

Rail traction return lines should see maximum d.c. voltages of +60V under normal circumstances and if directly connected to pipelines can cause significant interference and corrosion in a relatively short period of time. If one of the rectifier stations on a d.c. traction system was out of service, then the rail traction return circuit can see voltages in excess of +100V dependent upon the separation distance from the nearest d.c. traction system power source.

The maximum safety limit in terms of d.c. voltage is 60V and thus any rail traction circuit connections in any bond should be protected from accidental contact.

The typical separation distance between d.c. traction power sources on mass transit systems in the UK is in the region of 13 miles.

At critical bond locations suitable remote monitoring devices with monitoring facilities should be installed to provide an alarm to indicate when the pipe soil potential does not meet the specified criterion.

Resistors should be included in the bond circuit to control the level of d.c. current flow and a current measurement device e.g. shunt included so that the current flow through the bond can be measured. The resistors should be capable of adjustment and be rated to carry the maximum return current, which may be in the region of 10 to 50 Amps or even greater.

Diodes where installed should be rated at twice the maximum operating current and placed on a heat sink to help mitigate diode temperature rise. The PIV for the diode should be at least 600V. The design of any resistive bond should be subjected to a review by a suitably qualified specialist.

There should be two cable to pipe connections at rail bonds one to carry the current and the other used to measure the pipe to soil potential. If there is only one pipe connection cable installed and that cable is used for both current and potential measurement it should be noted that because of the cable voltage losses due to current flow accurate pipe to soil potentials may not be able to be recorded.

Wherever possible the use of unidirectional bonds should be avoided. However, if a directional bond is already in place prior to any decision to disconnect the bond exhaustive testing should be carried out to confirm that it would be safe to remove the bond. The pipeline operators Management of Change procedures should be followed for any specific changes to original interference mitigation system designs.

If a new pipeline to rail traction system uni-directional or even forced drainage bond is to be installed, then the bond design must be approved by the Railway Authority. They would typically have limits on any frequencies that could be present on the bond current particularly if it a harmonic of 50 Hz as this could affect rail signalling. In the case of forced drainage bonds, no 230V a.c supply would be permitted to be routed under railway circuits or lines only a 110V a.c. supply would be permitted.

Where 230V a.c supplies are installed at unidirectional or forced drainage bond locations then electrical inspection checks required on electrical equipment should be carried out by the pipeline Operator.

6.3.4 Installation of Sacrificial Anodes

Sacrificial anodes can be used to create a low resistance path for stray current to flow off an interfered pipeline at current discharge locations. The anodes should be electrically connected to the interfered pipeline and placed close to the interfering structure. The installation of sacrificial anodes connected to a pipeline can also be considered in areas of localised stray current discharge from the interfered pipeline, where the addition of an anode raises its pipe to soil potential to the required protection criteria.

Where sacrificial anodes are employed Schottky diodes may sometimes be used in the anode to pipe connection to control the current direction i.e. only permit current discharge off anodes not current collection by anodes. The use of Schottky diodes is discussed further in Section 9.10.

Sacrificial anodes may be used to counteract interference each side of an I/J from either a pipeline or an AGI CP system.

Sacrificial anode CP systems do not generally cause stray current interference if they operate at currents less than 100mA. The sacrificial anodes should be installed so that there is no third-party pipeline or structure between an anode and the pipeline under protection.

6.4 Direct Bonds

A metallic bond between the interfered and interfering pipeline either with or without a resistor can drain stray current away from the interfered pipeline to the interfering pipeline.

It would be important to check the operation of bonds on at least a monthly basis and where there is reliance on just a single bond to combat interference consideration should be given to the installation of at least one additional bond to provide an element of redundancy in case of inter-pipeline bond failure.

Where there is a direct bond to a number of pipelines e.g. at a drain point it is important to check that all cables have d.c. current flowing in them, since if one cable to pipe connection was to fail this could create a localised stray current interference location where corrosion could occur on the pipeline with the failed connection. It is therefore important that where such a situation may exist that the current flowing in all bond cables should be recorded on a regular basis.

Resistive bonds wherever possible should be avoided as experience has shown that these may fail during fault conditions e.g. high current surges or lightning strikes. They may also fail during routine operation and failure can affect the levels of interference on a pipeline system.

Resistive bonds require a higher level of maintenance and if installed should be capable of adjustment. Fixed value resistors should be avoided where possible.

Resistors should be designed to carry the required current without overheating.

The resistance of the installed resistor should be determined by monitoring the potential of the interfered structure, whilst adjusting the bond resistance, until the interfered structure achieves the specified CP criteria.

BS EN ISO 15589-1 [9] in relation to pipelines routed in parallel advises “Where pipelines are parallel, it is necessary to take precautions to ensure that there is no unacceptable interference or shielding. The interference can be the result of the influence of the applied cathodic protection, in which case the systems can need to be adjusted or the pipelines protected by a common cathodic protection system.

Where modifications to the cathodic protection or coating system are made on one pipeline, it shall have no adverse effect on the other pipeline(s).

To control current, bonds between two or more pipelines may be direct, or it can be necessary to include a diode, or a series resistor installed in a test facility.

Groundbeds should be located with due consideration to the risk of shielding and interference.

No work should be undertaken on a parallel foreign pipeline without the consent of its operator.

Note 1: Bonding parallel pipelines with widely differing cathodic protection current demands will probably not be successful. In some cases, separate cathodic protection systems will be required.

Note 2: When measuring pipe-to-electrolyte potentials on parallel pipelines that are not bonded, it is important that the reference electrode is located correctly and placed above the pipeline under test.

Where pipelines follow a common right of way and there are a number of different operators. A joint scheme is often employed where all pipelines are equipotential bonded to mitigate the risk of stray current interference. Inter pipeline bonds should be installed at regular intervals along the pipeline route e.g. every 2 to 5 km.

Where joint schemes are employed regular meetings between pipeline operators should be held to review operating performance data. The responsibilities for bond maintenance should be agreed between the respective pipeline operators and the operating current of all bonds recorded at periodic intervals.

6.5 Connections to Pipelines

Bonds between third party pipeline systems may be necessary in some instances but preference would be to avoid bonds wherever possible or practical. If a bond is installed between a pipeline and any third-party pipeline to combat stray current interference, then an agreement would generally be required to cover maintenance responsibilities between the respective pipeline operators.

Pin braze connections are not the preferred method of cable to pipe connection for bonds or drain point connections where the current exceeds 10A .They can be used on existing pipelines if the maximum current is less than 10A but where there is a current in excess of 10A or new pipeline connections are required welded cable connection plates are preferred even for CP monitoring facilities.

On new pipelines only a welded cable connection plate should be used for CP connections. Fully welded cable to pipe connections should be used for all current carrying connections where possible, but it should be recognised that welded connections may not always be practical on existing pipelines due to the requirements for welding on to live lines.

The requirements for welding onto live lines may vary between different operators and be dependent upon the product being transported.

Where bonds are installed consideration should be given to the use of remote monitoring to replace the monthly functional checks.

BS EN ISO 15589-1 [9] advises that "Where *a bonding facility at crossings with other pipelines is required, this should consist of two separate, suitably sized, conductors attached to each individual pipeline, terminating in a test station with facilities to install direct, unidirectional, or resistive bonds as required". It also recommends that where uni-directional drainage bonds are installed Visual check of the unidirectional drainage unit and reading of the integral cathodic protection instrumentation should be undertaken on a monthly basis*.

Pipeline operators should identify all bonds on pipeline systems and identify the structures to which a bond is made.

At drain point locations where, multiple pipelines are bonded it is particularly important to ensure all pipelines in a common right of way are electrically connected via a solid low resistance bond.

Conductive metal-based epoxies have been used to connect cable connection plates to pipeline systems. These connections cannot carry d.c. current long term and often fail. Even if there is no current flow the copper loaded epoxy cable connection method frequently fails, and operation life of this connection method is limited.

6.6 Crossing of Rail Lines

Pipelines crossing or running parallel with rail lines can suffer from d.c. stray current interference. It is essential to establish at an early stage during a pipeline design if the rail line is electrified and if electrified whether it is an a.c. or d.c. traction system.

The separation distance that should be considered between a.c. traction systems and pipelines routed parallel to a.c traction systems is given in BS EN 50443 [6] and similar distances should be considered for d.c. traction systems i.e. where pipelines are routed in parallel with traction systems closer than 25m significant levels of interference may be experienced.

Wherever pipelines cross d.c. traction circuits then the d.c. stray current interference risk should be considered and the separation distance between a traction circuit and a pipeline should exceed 3m.

For high pressure gas and oil pipelines the track system operators require a minimum separation distance of 3m between rail line and pipeline see PD-8010-1 [26] and IGEM/TD/1 [27].

The operating voltage of the rail line should be established, and discussions should take place with the railway operator to establish any specific requirements for interaction testing in accordance with BS EN ISO 21857 [1].

It is important to establish where the substations for the rail electrification system are located in relation to any pipeline route and crossing. Pipeline crossings of d.c. traction rail lines should be located as far as possible from the d.c. substations or Traction power substation (TPS). If a d.c. substation is taken out of service for any reason, then this can result in high rail traction return line voltages and increased levels of stray current interference on susceptible pipelines and affect the operation of unidirectional bonds.

If such a situation exists, then personnel working on rail bonds where there is an exposed connection to the rail traction return may exposed to an electrical shock risk.

If the d.c. voltage exceeds 120V then such a circuit will be classed as a low voltage circuit under the IET Wiring Regulations BS 7671 [28]. IEC 60364-4-41 [29] does however provide specific safety recommendation if the a.c voltage is greater than 25V and d.c. voltages in excess of 60V.

D.C. operated traction systems should be avoided if at all possible when a new pipeline route is selected. If it is not possible to avoid crossing a d.c. operated rail crossing it is recommended on new pipelines that I/Js are installed on the pipeline at each side of the rail line. The requirement for ER probes or similar corrosion rate measurement devices at high risk interference locations should also be considered.

Additional guidance on the use of ER probes or coupons to assess corrosion rates from d.c. stray current interference is given in Appendix G.

6.7 AC Interference on Pipelines Affecting D.C. Pipe to Soil Potential

If a pipeline system has levels of a.c. interference above 3.0V rms then there may be the risk that the a.c. voltage present on the pipeline could be rectified by variance and thyristor controlled CP T/R units and produce a fluctuating d.c. current output from the affected T/R unit. Fluctuating d.c. pipe to soil potentials on a pipeline could be as a result of a.c. interference on the pipeline rather than d.c. interference from other sources.

Typical variance-controlled CP T/R units and thyristor-controlled T/R units with a flywheel diode can rectify the a.c. voltage present on the pipeline and produce a fluctuating d.c. current output. This d.c. current flow can be reduced by installing a suitably rated choke on the T/R unit negative return cable to reduce the a.c. voltage at the rectifier bridge.

If it is suspected that the a.c voltage on a pipeline is causing d.c. current variations on a T/R unit then a data logger should be installed in the T/R unit on a temporary basis to confirm, whether there is a varying d.c. current output being provided from the T/R unit.

The data logger should be used measure the voltage drop across the shunt in the T/R d.c. current output to check if there is any time dependent variation in T/R unit d.c. current output. In addition, both the a.c and d.c. pipe to soil potential variation at the CP drain point should also be recorded at the same sampling frequency and time.

6.8 Crossing of Third-Party Pipelines

It is important to establish at an early stage the requirements of any third-party pipeline operator in terms of test and monitoring facilities for stray current interaction testing, If a new pipeline is to cross an existing pipeline, then consideration should be given to the need for reference electrodes and coupons at the crossing points to assist in stray current interaction testing at a later date.

The coupons and reference electrodes would need to be installed at the crossing point and routed back to a suitable CP test facility located at a field boundary during pipeline installation. Detailed information on stray current interaction notification and testing requirements is given in Appendix E.

6.9 Crossing of Power Cables

Pipeline crossings of a.c. and d.c. power cables should be made at right angles and at a separation distance of at least 0.6m but preferably 1m. For high voltage cables > 33kV

The separation distance should be at least 1.0m. The cables should cross the pipeline in a duct to provide mechanical protection and no bare earth conductor shall cross the pipeline or be installed at a distance close to a pipeline that will create a hazardous touch potential during fault conditions. The maximum a.c. touch potential limit should be based upon the guidance given in BS EN 50122-1 [30] and will be dependent upon the disconnection time for the protective devices.

6.10 Use of Isolation Joints

In the case of new pipelines or diversions of existing pipelines that are susceptible to d.c. stray current interference then splitting a pipeline into electrically discrete sections by the use of isolation joints should be considered by the designer to mitigate the d.c. interference risk. It is important that prior to use all I/Js are checked to confirm they have the required insulation resistance.

The typical insulation resistance specified for I/Js is ≥ 5M Ohm and the test voltage is 500V.The use of I/Js can limit the stray current interference effects to specific sections of a pipeline system and is often used in the UK on new pipeline systems where they cross d.c. operated rail lines or where diversions of pipeline systems are required for a new d.c. traction system.

Where I/Js are installed to combat interference then facilities to enable the I/Js to be bonded if required should also be included in the design.

Test facilities should be installed on a pipeline at each side of a railway crossing. The test facilities should include at least two cables connected to the pipeline each side of an I/J one for potential measurement minimum conductor size 10mm^2 and one minimum conductor size of 25mm^2 for current carrying connections e.g. where a bond is or maybe employed to allow for the possibility of bonding across an I/J if required. Preference would be to avoid the installation of bonds either forced drainage or unidirectional bonds.

Test facilities each side of an I/J should be separated by at least 3m to mitigate any touch potential risk. At rail crossings a buried permanent reference electrode and 1cm^2 exposed surface area should be installed so that the d.c. interference current levels can be monitored.

The CP system designer should also consider whether there is a requirement for any sacrificial anodes to discharge stray d.c. current especially at I/Js.

6.11 Calculations to Determine D.C Interference Levels

The voltage rise U_X at a distance of x m from a CP groundbed can be calculated by the formula provided in Annex D of BS EN14505 [23], The potential rise at a distance x is dependent upon whether the groundbed is horizontal or vertical, Equation 8) provides the calculation methodology to determine the voltage rise on a pipeline from a horizontal groundbed

$$U_x = \frac{I\rho}{2L} \times \left[Ln \left(\frac{S+L+\sqrt{r^2+(S+L)^2}}{S+\sqrt{r^2+S^2}} \right) \right] \qquad 8)$$

Where I= Groundbed Current Amps
ρ= Soil resistivity Ohm m
S= Groundbed depth m
L= groundbed length m
r= Distance r from groundbed in m
Ux = Voltage at distance x from groundbed
U_A = anode voltage to pipeline measured against remote earth

$$U_A = \frac{\rho I}{4\pi L} \left\langle \ln \left[\frac{L+\sqrt{d^2+L^2}}{-L+\sqrt{d^2+L^2}} \right] + \ln \left[\frac{L+\sqrt{(4t-d)^2+L^2}}{-L+\sqrt{(4t-d)^2+L^2}} \right] \right\rangle \qquad 9)$$

Figure 8 shows the potential rise on a pipeline from a horizontal groundbed at a distance x from the pipeline in relation to the % voltage at the groundbed. To ensure that the levels of interference from the groundbed are low the % voltage loss in relation to the anode voltage at the pipeline should be at least less than 5% and ideally 2% as determined

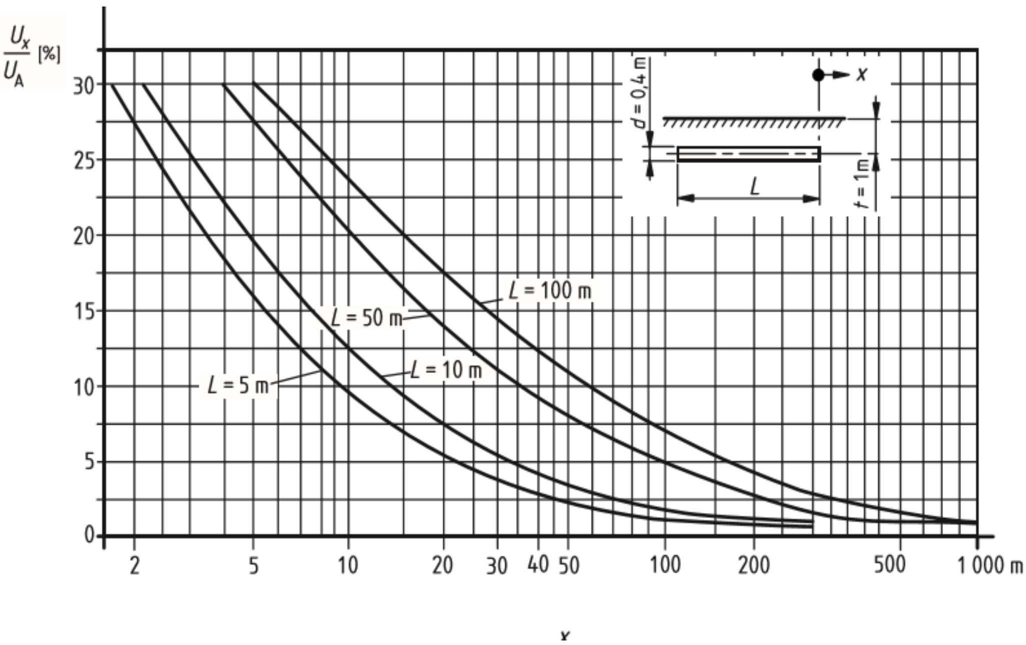

Figure 9 Variation in Potential Rise with Distance from Horizontal Groundbed with Groundbed Length Extracted from BS EN 14505

The guidance in BS EN 14505 and the graph shown in Figure 9 has been based a publication by Baeckmann and Schwenk [31]

Baeckmann and Schwenk states that “Horizontal impressed current groundbeds of 100m or more in length usually behave as extended voltage cones. Figure 9 above (Figure 9.5 in Baeckmann and Schwenk [31]) shows that at 100m from the anode bed 7 to 10% of the anode voltage still exists as measured against the remote earth and only falls to 1% at a distance of 1000m from the groundbed. The size of the voltage cone is of importance in determining the likely interference with foreign pipelines “.

The lower the % of anode voltage seen at the third-party pipeline the lower the interference. Some designers require the anode voltage % loss to be less than 5% to limit stray current interference but clearly the lower the % voltage loss the better and ideally values less than 2.5% should be considered.

Groundbeds that are of appreciable length and operate at high current would need to be an appreciable distance from a third-party pipeline and a separation distance considerably in excess of 100m would be required.

The guidance in Appendix E2.2 is that a separation distance of at least 400m should be considered as the separation distance between third party pipelines and groundbeds. However, if groundbeds are of reduced length and current output separation distances less than 400m can be considered to limit interference effects based upon Figure 9.

The voltage rise on a pipeline from a vertical groundbed is given in Annex D of BS EN 14505 [23].

7. DC INTERFERENCE MITIGATION AND PIPELINE DESIGN CODE REQUIREMENTS

The pipeline design and integrity management code standards In the UK e.g. PD 8010-1 [26], PD 8010-4 [32], BS EN 14161 for oil and petroleum product pipelines or IGEM/TD/1 [27] and IGEM/TD/3 [33] in the case of natural gas pipelines in the UK provide limited guidance in relation to d.c. interference.

Operators should note that whilst pipeline design standards do give guidance on pipeline corrosion management, they do not address the d.c. stray interference risks in any detail and refer either to BS EN 50162 [2] or BS EN ISO 15589-1 [34].

BS EN ISO 15589-1 [34] does give some limited guidance on stray current interference but mainly refers pipeline operators to the guidance given in BS EN 50162 [2], which has now been replaced by BS EN ISO 21857 [1].

In the case of d.c. interference from rail traction systems in the UK the guidance given by the Office of Rail Regulator in Tramway Technical Guidance Note 3 [18] should be followed in addition to that stated in BS EN ISO 21857 [1]. The Safety Management Guidelines given in RSSB GE/GN8644 [35] also apply to interference from d.c. traction systems.

Guidance in relation to d.c. interference from solar farms should be supplemented by the guidance given in this GPG, BS EN ISO 21857 [1] and UKOPA/GPG/014 Edition 1 [3]

It is recommended in this GPG that any d.c. interference monitoring, and mitigation systems designs should be carried out by personnel having the levels of competency and certification defined in BS EN ISO 15257 [36].

Stray current interference monitoring, and mitigation system designs should be carried out by a BS EN ISO 15257 Level 4 Cathodic Protection Specialist.

Pipeline operators should nevertheless confirm that personnel employed in design and monitoring on pipelines susceptible to d.c. interference even if BS EN ISO 15257 [36] certified do have the requisite levels of experience and competency in assessment of d.c. interference risks on pipelines.

Certification of personnel to BS EN ISO 15257 [36] may not always provide the required level of awareness in relation to the safety risks associated with work on electrically operated equipment or issues associated with d.c. stray current interference.

Pipeline operators should confirm the competency of any personnel and specialists employed and provide relevant training to operations personnel where necessary. D.C. stray current interference monitoring and assessment requires skills that some CP monitoring personnel may not possess, and specialised training is advisable to cover d.c. stray current monitoring and assessment.

8. SPECIFIC REQUIREMENTS DC INTERFERENCE

8.1 Training and Awareness

Where pipeline failures have occurred as a result of d.c. stray current interference or incorrect polarity of CP systems these are often associated with a lack of awareness of the possible risks of stray current interference by pipeline operations personnel and senior managers.

It is important that operators ensure that not just CP technicians and engineers are aware of the possible risks and consequences of d.c. stray current interference but that senior managers within an operator's organisation also have an understanding of the risks.

This is to ensure corrosion failures due to stray current are prevented by suitable design, operation and maintenance procedures.

The nature of the work on pipeline systems that may pose a d.c. stray current risk would involve modification to CP system transformer-rectifiers, failure of uni-directional and forced drainage bonds and d.c. welding operations.

Personnel undertaking routine monitoring of d.c. interference on pipelines should have the required levels of competency, certification and understanding and be fully conversant with the relevant safety and accelerated corrosion risks associated with d.c. interference.

It is important that risk assessments and method statements are produced for stray current interference monitoring and personnel undertaking the work should comply with the relevant risk assessments and method statements together with any other specific pipeline operator safety requirements

In the case of work on T/R units or forced drainage bonds where there is a 230V a.c supply present then the electrical competency requirements defined in the pipeline operators management procedures for working on or near electrical systems should be followed.

8.2 New developments within the Vicinity of Existing Pipelines

If any new developments are planned within the vicinity of an existing pipeline for a distance of up to 500m from the pipeline system, then the effect that such developments may have on the integrity of pipeline systems should be established, and the Operator's Asset Integrity Engineer consulted.

This will assist in ensuring that any possible risks of d.c. interference are assessed at an early stage and preferably before planning permission is granted.

The nature of any new developments that would create a d.c. stray current risk would include, new HVDC substations and power cable systems, new cathodically protected pipeline systems, solar farms, d.c. operated traction systems, industrial sites and large-scale battery energy storage sites. All the latter systems have the ability to create d.c. interference that may affect the integrity of pipeline systems.

Power sources that can provide significant d.c. fault currents e.g. HVDC systems, rail traction systems, battery energy storage sites and solar farms are of particular concern. It is important to establish the d.c. fault current magnitude, together with the frequency and duration of faults at locations in close proximity to buried pipelines as this will determine the accelerated corrosion risk.

Details of the electrical characteristics of any new d.c. operated electrical systems should be established with the facility promoter or developer.

8.3 Solar Farms

8.3.1 General

Solar farms or PV farms can produce stray d.c. current during normal operation and during fault conditions. The electrical details of the solar farm installation should be established with the Promoter of any new solar farm.

UKOPA has given guidance on siting of solar farms in close proximity to buried pipelines in GPG UKOPA/GPG/014 [3].

BS EN ISO 21857 [1] also provides supplementary guidance on d.c. interference from solar farms.

The a.c. interference risks associated with solar farms should also be considered but these are outside the scope of this GPG.

Solar farms can act as a source of both short and long-term d.c. current leakage and should be located as far as possible from buried pipelines.

Figure 10 indicates the effects of d.c. stray current interference from solar farms and has been extracted from a paper by Demetriou, Buxton and Charalambous [37] on the d.c. interference effects from solar farms.

A number of technical papers haven produced on modelling d.c. stray current interference from PV farms and on stray current corrosion on pipelines from isolated PV systems and the publications detail the factors that should be considered by pipeline operators. [38] [39] [40]

There are two issues to consider in relation to solar farms one is the long-term d.c. leakage current and the other is short term d.c. current during fault conditions. Promoters of new solar farm systems should undertake an assessment of the likely risk of d.c. stray current interference on buried utilities and advise the pipeline operator accordingly.

Details of the short-term d.c. fault current magnitude and the disconnection times of protective devices should be advised to the pipeline operator together with information on the anticipated fault frequency. The PV operator should also advise if the d.c. current leakage magnitude will have any seasonal variation.

In the context of large-scale PV systems, d.c. stray current corrosion may have a significant impact on the grounding electrodes and the metal foundation of the PV plant supporting infrastructure, as well as on any third-party infrastructure (e.g. pipelines)

The levels of stray current interference can show seasonal variations. The winter months may see lower ground electrode resistance values and hence higher leakage currents and in the summer months the stored energy from the PV system will be higher and thus a greater fault current capacity may exist.

The d.c. leakage current from cables can be relatively low and in the order of mA but if earth cables are routed in close proximity to pipelines even at currents as low as a few mA this can result in stray current interference on buried pipelines.

Even small d.c. leakage currents can have significant stray current interference effects on well coated pipelines.

Solar Farm operators should confirm that there will be no d.c. leakage current or that the d.c. leakage current will not pose a risk to buried pipelines.

On some projects solar farm electrical engineers have confirmed that the d.c./a.c. inverters continuously monitor for any d.c. fault current and they perform an insulation resistance checks at regular intervals. The insulation resistance of the solar farm from earth should be monitored by the PV operator

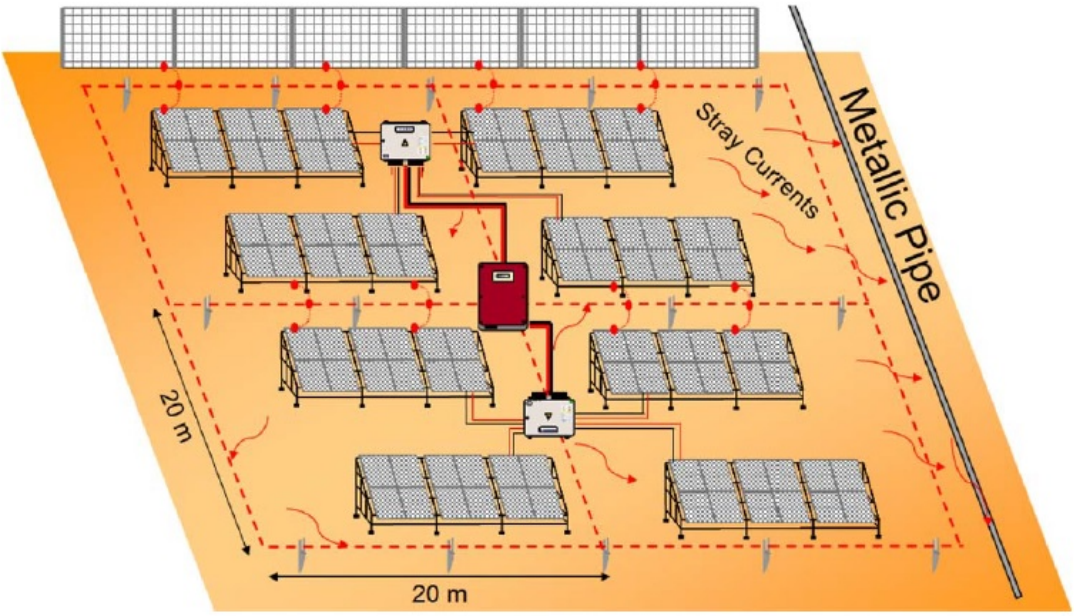

Figure 10 Schematic stray current from solar farm

For a certain d.c. voltage level, the d.c. leakage current is dependent on the effective insulation resistance (R_{iso}) of the system. The effective insulation resistance should be measured before connecting the PV system to the power grid will provide an indication of the magnitude of the anticipated leakage currents to ground [41].

Ground fault detection devices should be installed to advise of situations where d.c. current leakage can occur. Stray current interference from PV farms is a time dependent process as it will depend on ground conditions and levels of solar radiation.

The maximum theoretical d.c. fault current for strings connected to the same MPPT input should typically give a maximum fault current of less than 100A (dependent on sunshine levels). The protective devices should clear the faulty within less than 200 milliseconds (<200ms) and this should not create a significant metal loss risk on a pipeline.

When such faults occur, this should provide the solar farm operator with an alarm on a monitoring portal. If alarms or faults occur the pipeline operator should be notified. Pipeline operators need to ensure that this is included in any agreement.

However, failure in the d.c. strings can result in d.c. current leakages (<1A) and would be of concern to the pipeline operators. If the solar farm operator experiences low level d.c. current leakage this can cause interference on pipelines and pipeline operators should be notified.

Liaison between the PV operator with the pipeline owner is required to assess the risk. Specialized audits at regular intervals may be necessary including measurement and monitoring. The PV operator may have to consider the cost of increased infrastructure inspections and retrofit monitoring devices against the potential cost and damage from d.c. stray current. corrosion.

In cases where the level of stray current cannot be controlled to acceptable levels, measurement and monitoring of the third-party assets may be required, with mitigation applied to the affected structure if required.

The typical layout of a pipeline routed through a new solar farm installation is shown in Figure 11. The requirements for evaluation and testing in relation to solar farms are detailed in the following sections.

Figure 11 Aerial view of pipeline (yellow line) routed through solar farm

8.3.2 General

Solar farms within the vicinity of pipelines can cause issues in relation to d.c. stray current interference and impact on other aspects of pipeline monitoring and operation. At the design phase of any new solar farm installation full details of the electrical specification for the PV system should be provided by the Developer.

The Developer should identify the measures taken to address the d.c. stray current interference risks on any pipeline system and the magnitude of the likely a.c/d.c. fault current and GPR on the pipeline system in the event of any d.c. and a.c. fault condition.

The Developer of new solar farms should liaise with the pipeline operator and confirm that there will be no detrimental effect from the new PV system on buried pipelines and confirm that the PV system has the required electrical insulation resistance. Ground fault protection devices should be installed in the PV system and provide an alarm in the event of fault conditions. The pipeline operator should be notified in the event of any condition.

Cables for the PV system should be installed in ducting so as to minimise current leakage and the PV system operator should confirm to the pipeline operator the measures taken to reduce the stray current interference risks to the pipeline system during both long term and fault conditions.

No bare earthing system or electrodes for the PV system should be installed within 10m of any pipeline. Any cable crossing of the pipeline should be in ducts and no bare earth conductors shall be permitted

Crossing of plant and equipment of any pipeline shall comply with established industry procedures to prevent damage to pipelines and shall be agreed in advance of the works. In certain circumstances pipeline operator Management of Change procedures should be followed to confirm the suitability of any pipeline crossing arrangement.

There should be sufficient space between a pipeline and the PV farm infrastructure to allow access for over the line surveys and for the operator to have access for future repairs.

A CP test facility should be installed in close proximity to the PV installation to enable routine monitoring and any stray current interaction tests to be conducted. The CP test facility may need to be located at the nearest suitable boundary, but any coupons and references electrodes should be located close to the pipeline. New CP test facilities should include a coupon with a 1 cm^2 exposed surface area and a permanent buried reference electrode as a minimum requirement.

Consideration should be given to the installation of remote monitoring facilities within any new or existing test facilities. In certain circumstances the use of a remote monitored ER probe may be considered.

8.3.3 Pre-energisation Tests

Prior to energisation of the solar farm baseline data logging should be conducted at the nearest CP test facility or test facilities to the PV installation. If there is no CP test facility close to the installation, then new CP test facilities may be required prior to construction of the solar farm.

Data logging should ideally be carried out at different times of the year, one of which should be in the summer months. Data logging should be carried out at the minimum of two test facilities each side of the PV installation and shall include measurement of a.c. pipe to soil potential, d.c. pipe to soil potential and a.c / d.c. current density through the coupons. Data logging should be carried out at a minimum of 1 to 2 second intervals over a representative period of time between 48 hours to 7 days.

Where the PV farm is routed close to a pipeline a base line CIP survey and suitable coating defect survey e.g. ACVG or DCVG survey technique approved by the pipeline operator shall be conducted prior to construction. The CIP and coating defect survey shall cover the whole length of the proposed new solar farm plus at least 500m each side of the solar farm. The precise location of any coating defects shall be confirmed, and the location of any coating defect no matter how small should be recorded.

8.3.4 PV System Energisation Tests

Prior to energisation of the solar farm i.e. at least 24 hours in advance of energisation a data logger should be placed into the nearest CP posts each side of the installation. The date and time of the energisation should be agreed between the pipeline operator and the developer.

The solar farm system may then be energised, and data loggers installed to monitor the time dependent variation of d.c. pipe to soil potential and current density. Data logging should be carried out at 1 to 2 second intervals.

To supplement the test regime the pipeline operator may request that the PV installation is switched ON and then OFF to confirm if there any changes in the pipe to soil potential local to the PV farm. Post construction of the solar farm a CIP survey and a repeat coating defect survey should be conducted on the entire length of the pipeline routed through any new solar farm and also on the pipeline at least 500m each side of the development.

8.3.5 Long Term Monitoring PV System

It would be important to continue using data loggers at periodic intervals to monitor the time dependent variation of pipe to soil at test facilities within the vicinity of the PV station to provide confidence that the longer-term levels of interference are within acceptable limits.

Consideration should also be given to the installation of a remote monitoring device to provide an indication of an alarm situation on the pipeline in the vicinity of the PV system. It will be important on large scale PV developments that the pipeline operator has an agreement to cover work on the pipeline and possible interference scenarios.

Data from the post energisation tests should be reviewed by a suitably competent expert in analysis of stray current data

8.3.6 BS EN ISO 21857 Recommendations

BS EN ISO 21857 [1] advise that certain factors should be taken into account in assessing the size of PV interference or to mitigate it are:

At the source level:

a) *For detecting d.c. leakage faults in grounded PV systems, the installation of a Ground Fault Protection Device (GFPD) should be considered. These devices are designed to interrupt the flow of d.c. fault currents and also to alert about fault occurrences.*

b) *Ground fault detection in floating PV systems (isolated & non-isolated) is typically achieved by monitoring the DC insulation resistance from the PV input (array) to ground. The measurements are typically achieved by monitoring the insulation impedance of each pole (positive and negative) relative to ground. The measurements are achieved by the use of embedded insulation monitoring devices (IMDs) and they usually take place before inverter starts operation.*

c) *If the d.c. cables of the PV system are placed in plastic conduits, then any d.c. leakage to ground arising from these cables will be limited.*

At the pipeline level:

- *The extent of stray current corrosion damage on a nearby pipeline would be specific to the characteristics and topology of each large-scale PV installation. It will also be specific to the relative position of the buried pipeline with respect to the faulted sections of the PV system.*

- *Liaison with the PV operator with the utility company is required to assess the risk. Specialized audits at regular intervals maybe necessary including measurement and monitoring. The PV operator may have to consider the cost of increased infrastructure's inspections and retrofit monitoring devices against the potential cost and damage from d.c. corrosion.*

8.4 D.C. Welding Operations

D.C. welding operations during pipeline construction and repair can cause stray current interference and corrosion on metallic structures if carried out incorrectly.

D.C. welding on pipelines requires welding sets that operate at currents between 50 to 400 A. In general, for most pipeline construction operations the current required for the welding processes will vary between 75 A for a 2.4mm electrode to 225 A for a 5mm thick weld electrode. Typical current values during pipeline construction would be in the region of 90 to 140 Amps dependent upon pipe wall thickness and diameter.

D.C. welding operations generally require the welding electrode to be connected to the d.c. positive terminal of the welding set to maximise the heat input into the weld. The component to be welded should then be connected to the negative terminal on the welding generator. The negative return connection should be made as close to the component being welded as possible.

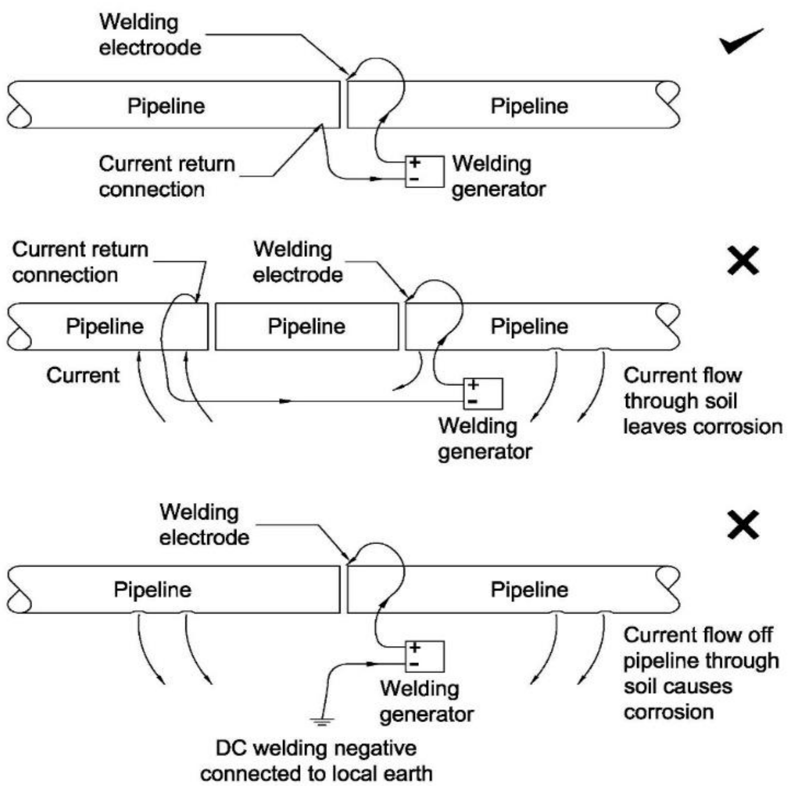

Figure 12 Examples of situations that could lead to stray current interference during welding operations

If the d.c. negative connection is not connected to the component to be welding but to another earthed structure as shown on Figure 12 then there can be current flow off the pipeline to the welding generator through the general mass of earth. In such a situation this current flow can result in significant damage and metal loss on a pipeline in a relatively short time.

Significant metal loss can occur in a relatively short period of time due to stray current interference. Generally, inspection and construction personnel are not aware of the enhanced corrosion risk associated with incorrect operation of d.c. welding systems. However, there have been instances where incorrect connections to welding generators have been made and as a result corrosion has occurred on a pipeline and that has resulted in localised metal loss in the region of a few mm in a relatively short period of time.

It is important that welders and welding inspectors are aware of the stray current risk from d.c. welding operations and ensure the correct polarity of welding connections. It is essential that the return connection is made as close to the field weld or component to be welded as possible.

Figure 12 shows examples of situations that can result in stray current corrosion of pipelines by welding operations during pipeline construction.

The first sketch in Figure 12 shows how the welding operations should take place with the connection made to the component to be welded, examples of poor construction practice that can lead to stray current corrosion are also detailed on Figure 12. D.C. welding operations during pipeline construction and repair can cause stray current interference and corrosion on metallic structures if carried out incorrectly.

8.5 Third-party CP Systems

Where pipelines are routed in close proximity to or cross other cathodically protected pipelines. There is a risk of stray current interference from the third-party pipeline CP system on an operator’s pipeline.

The level of stray current interference is dependent upon the separation distance between an operator’s pipeline and any third-party pipeline groundbed and the operating current of the third party groundbed or groundbeds. The older the third-party pipeline system the higher the current demand and higher the current output from any groundbed.

For new pipeline systems it is essential that the location of all third-party pipeline groundbeds within 500m each side of the proposed pipeline route are identified so that the CP system design can ascertain if there is a stray current interference risk. It also important to establish if there any other cathodically protected pipelines or structures also a pipeline route.

Where different operator pipeline pipelines are routed in parallel then inter pipeline bonds may be required to mitigate the stray current interference risk

The requirements for stray current interaction testing on pipelines from other pipeline CP systems are detailed in Appendix E.

Stray current interaction testing applies to both new and existing crossings of pipelines with third party pipelines or rail traction circuits both a.c. and d.c.

8.6 Incorrect Polarity of CP systems

8.6.1 General

CP T/R units can be wired up incorrectly i.e. the pipe connected to a groundbed terminal on a CP T/R unit and the groundbed connection on a T/R unit connected the pipeline or d.c. negative terminal.

This could happen where electrical personnel make a connection on the d.c. output of a T/R unit and may not be aware of the risks associated with enhanced corrosion on a pipeline by incorrect polarity of connection on d.c. power sources.

If a suitably qualified CP engineer does not make the connection on the d.c. output such a situation can happen. Incorrect cable colours or the use of the same cable colour for both d.c. negative and d.c. positive cable connections can lead to confusion and result in incorrect cable connections to CP T/R units being made and the pipeline being inadvertently connected to the T/R unit d.c. positive.

If such a situation happens i.e. incorrect connections are made within a T/R unit then accelerated corrosion on a pipeline can occur and can lead to failure of a pipeline system or result in significant levels of damage in a relatively short period of time.

CP T/R units should be checked to confirm that they have the correct polarity of d.c. output. If for example the CP negative cable is disconnected on a temporary basis to prevent damage to any T/R unit when welding operations take place, remote monitoring switching units are installed, groundbeds are replaced or new T/R units installed. Then it could be the case that a T/R unit may be rewired incorrectly.

Incorrect polarity of connection of T/R units can and does happen. It is mainly associated with a lack of awareness amongst electrical personnel of the effects of incorrect polarity of connection and the knowledge that d.c. current can cause significant levels of metal loss under certain circumstances.

It is essential that the d.c. negative terminal on CP T/R units is connected to the pipeline and the d.c. positive to the groundbed. This applies to both new installations and modifications to existing installations.

In such situations it would be advisable to have a suitably qualified CP engineer confirm that the polarity of the connection is correct and a certificate issued to confirm that the CP T/R unit output polarity has been confirmed as correct when it is energised.

Where a remote monitoring system is installed on a T/R unit or pipeline system the alarm settings on the remote monitors shall be selected to indicate a positive change in potential of the pipeline on increase in T/R unit current and advise on a situation that requires immediate investigation.

8.6.2 Specific Requirements Work on T/R units

Modifications to CP T/R units should be carefully conducted to avoid any reverse polarity. It is also important that electrical personnel are given appropriate training and awareness of the risks associated with d.c. stray current and incorrect polarity of connections.

All d.c. positive cables should be coloured red and where other cable colours have been used for termination at a CP T/R unit groundbed terminal then red insulating tape should be fitted on the cable to indicate a d.c. positive circuit.

D.C. negative current cables should be coloured black. If the negative cable colour is not black, then black insulating tape should be fitted. Proprietary cable markers should also be used to identify all cables either by bearing the inscription PIPE or GROUNDBED as appropriate or be given a unique cable number.

All terminals within T/R units should be clearly marked Pipeline or Groundbed as appropriate and cables colour codes with red indicating d.c. positive circuits and black d.c. negative.

The d.c. output polarity of any T/R unit should also be confirmed as being correct.

8.7 HVDC Power Systems

8.7.1 HVDC System Operation

HVDC transmission systems can cause stray current interference on buried metallic structures. It is known that problems have been experienced on pipeline systems in other countries from HVDC power transmission systems.

D.C. current leakage from a HVDC substation earth can occur during normal operating conditions, when there are changes in the operational configuration of the HVDC system or during faults on the HVDC system and these conditions can result in d.c. stray current interference on buried metallic pipelines.

Overhead HVDC cable transmission systems cause higher levels of interference than buried HVDC cable systems because the overhead aerial earth wire will bond all the pylons together.

The further apart the HVDC converter stations are from each other the lower the risk of stray current interference on buried utilities.

A proportion of the d.c. leakage current from a HVDC system can return to the d.c. power source through the general mass of earth and some of that current can flow along buried pipeline systems within the vicinity of the power source, as pipelines would provide a low resistance path for the flow of current to the power source. In the case of HVDC transmission systems the current flow could be in the region of 1000A and the d.c. leakage current in the region of 0.05 to 10A. This leakage current can flow to earth on a continuous basis.

On older HVDC systems the d.c. leakage current can be at the higher end of the leakage current range but on modern HVDC systems the d.c. leakage current is claimed to be relatively low in the order of mA. The Promoter of any new works should advise the magnitude of d.c. leakage current during normal operation and fault conditions.

It should be noted that HVDC power cable operators are generally reluctant to provide information on the levels of d.c. current leakage but such information is important for pipeline operators to assess the levels of risk to a pipeline.

The current leakage from HVDC systems could result in significant levels of d.c. stray current interference on buried pipeline systems, as that current could be continually injected into the general mass of earth and cause sections of a pipeline system act as an anode.

Figure 13 shows a bipolar HVDC circuit arrangement and in bipolar mode there is limited flow in the earth circuit but there may be some current flow due to slight in balance in voltages between the positive and negative circuits

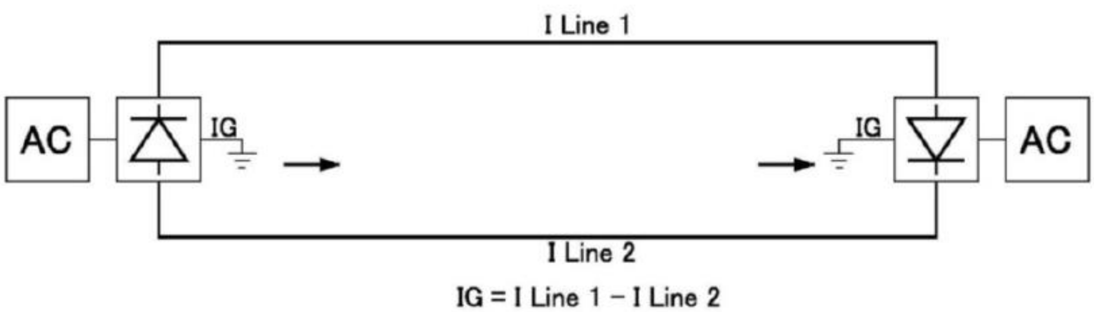

Figure 13 Bipolar HVDC System

It should be noted that the extent of long term d.c. interference will be dependent upon the magnitude of d.c. leakage current and where in relation to the pipeline the current is being injected into the general mass of earth. The current leakage to earth will be dependent upon the electrical specification for the HVDC system, which should be established with the power system operator at the design stage of any new HVDC system.

If stray current is produced by a HVDC system the stray current can cause changes in the pipeline to soil potential at the current discharge point, which can produce an anodic condition, that may result in corrosion and would need to be controlled. At the current injection point into the pipeline the pipe to soil potential changes will shift the pipeline in a negative cathodic direction.

Thus, a pipeline may corrode over time at a coating defect, if it is subjected to significant levels of interference that result in anodic condition.

No corrosion should be experienced on the pipeline where current enters the pipeline as the pipeline will be cathodically protected at that location. However, where current leaves the pipeline system to return to the d.c. power source an anodic condition will be experienced, and corrosion will occur.

There may be fault or maintenance conditions or other specific periods of time when one leg of a HVDC circuit may be out of circuit and then the system will operate in monopolar mode and significant current can flow through the general mass of earth see Figure 14.

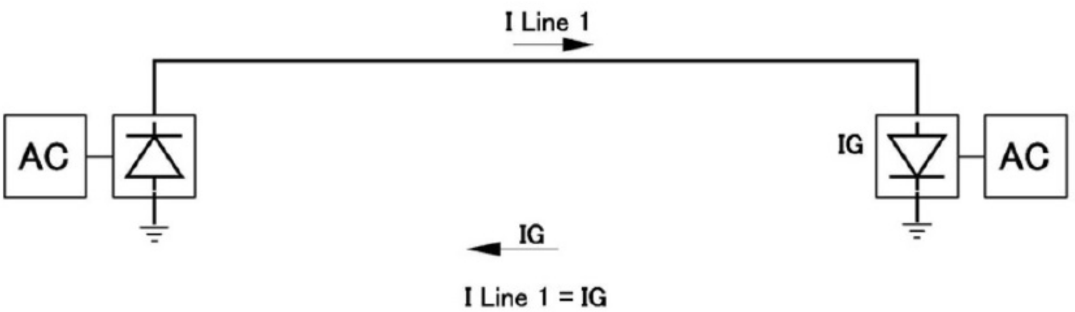

Figure 14 Monopolar HVDC System Operation

It should be noted that if excess levels of current enter a pipeline at a given location then this can result in high negative pipe to soil potentials and can cause cathodic disbondment of the pipeline coating, which could lead to detachment of the pipeline coating and corrosion of the pipeline under the disbonded coating. Thus, current entering a pipeline system can also result in problems if excessive negative potentials are achieved.

During fault conditions on HVDC power lines the current flowing through the general mass of earth could be significant and in the order of a few thousand amps for the duration of time taken for the protective devices to operate. The high current could cause significant metal loss even if it only flowed for a few hundred milliseconds.

Modern HVDC systems can disconnect within very short periods of time and the protective devices employed typically operate within 100ms. The exact period of time required for the disconnection devices to operate should be established with HVDC operator. If the fault current magnitude was 10kA and it occurred for 100ms this would result in 1,000 Coulombs of charge flowing to earth. 190,000 Coulombs are required to consume 55.845 grams of iron thus 1,000 Coulombs would result in a metal loss of 0.294 grams. If this metal loss occurred over a 1 cm^2 surface area then the pipeline metal loss would be 0.4mm, if the loss occurred over a 0.1cm^2 exposed steel area then the loss would be 4mm.

Thus, a single fault would be unlikely to cause failure on a pipeline but multiple faults over a prolonged period may well result in damage to a pipeline.

There may also be situations where one of the circuits is not operating and the earth will act as the return conductor. During such situations there could be significant levels of stray current interference. The cable system operator should at the early stages of the HVDC cable system design conduct a study of all the likely risks to any buried pipeline within the vicinity of the HVDC system. The HVDC power system operator should advise the pipeline operator of any situations associated with the operation of the HVDC system that could lead to interference.

8.7.2 Specific Concerns HVDC Systems

HVDC system operators should comply with the guidance given in BS EN ISO 21857 [1] in relation to d.c. interference from HVDC systems.

The converter station earthing system should be located as far as possible away from third party pipelines so as to ensure that pipelines are not located in the voltage field from the earthing bed that would be created during a fault condition or longer term leakage current event. The HVDC converter earth resistance should be as low as practical.

There are also safety concerns associated with touch and step potentials during fault conditions on the HVDC system. These would also need to be addressed during any review of the HVDC system by the cable operator.

It should be noted that the d.c. voltage magnitude above which measures need to be in place to prevent accidental contact is 60V, as opposed to 25V for a.c. voltages see IEC 60364-4-41 [29].

In the case of onshore buried HVDC cable systems typically employed in the joint bays are installed along the cable route at regular intervals where the power cables are jointed. Joint bays should be located remote from any pipeline to minimise the maximum GPR in the event of a cable fault and in the case of overhead HVDC power cable routes pipe to pylon separation should be maximised to limit stray current interference effects.

It should be noted that not all joint bays may have earthing.

D.C. leakage currents from any earthing installed at joint bays or pylons can also cause localised stray current interference and latter risk should be assessed as part of any d.c. stray current interference studies.

Pipeline operators should also note that where a HVDC converter station is installed then the load on overhead a.c. power cables in the vicinity of any d.c./a.c. converter station can increase and can result in increased levels of a.c. interference on buried pipelines simply because of the increased power load on adjacent overhead cables.

Operators need to consider the later risk and possibly undertake mathematical modelling studies using proprietary software to ensure that the d.c. interference levels on affected pipelines are within the limits prescribed in BS EN ISO 21857 [1].

Additional guidance on HVDC interference is given in NACE Publication 05114 [42].

8.7.3 HVDC converter station and cable crossing stray current monitoring designs

The CP system monitoring systems on pipelines that may be affected by stray current interference from HVDC systems should be assessed to ensure that they are sufficient to ensure that the levels of d.c. interference created by any HVDC system can be monitored. This would at the very least mean ensuring that there are coupons installed at CP test facilities.

At HVDC cable crossings of pipelines new CP system monitoring facilities should be installed. It is recommended that where pipelines are routed close to HVDC converters or cable joint bays that ER probes capable of remote monitoring are installed. This will enable pipeline operators to confirm if any short-term fault current effects have resulted in metal loss and provide an alarm indication.

8.7.4 Pre-energisation tests HVDC systems

Prior to energisation of the HVDC cable systems and convertor stations baseline data logging should be conducted at the nearest CP test facility or test facilities to the installation. If there is no CP test facility close to the installation, then new CP test facilities may be required prior to construction of the HVDC system.

Data logging should be carried out at a number of test facilities along the pipeline system that may be affected. The CP test facilities should have as a minimum a $1cm^2$ exposed surface area coupon and a buried permanent reference electrode. If the existing test facilities do not have any coupons, then they would need to be modified.

The data logging should include measurement of a.c. pipe to soil potential, d.c. pipe to soil potential and a.c / d.c. current density through the coupons. Data logging should be carried out at a minimum of 1 to 2 second intervals over a representative period of time between 48 hours to 7 days. Data logging would provide a good set of baseline data so that it can be established whether any new HVDC system has created any additional stray current interference risks.

A base line CIP survey and suitable coating defect survey e.g. ACVG or DCVG survey technique approved by the pipeline operator shall be conducted prior to energisation of the HVDC system. The CIP and coating defect survey should cover the whole length of the pipeline system that it is considered will be affected by the new HVDC cable system. The location of all coating defects should be confirmed, and any coating defect no matter how small should be recorded.

8.7.5 HVDC System energisation tests

Prior to energisation of the HVDC at least 14 days advance notice of energisation shall be given to the pipeline operator. A data logger should be placed into the nearest CP posts to the HVDC installation the installation.

The HVDC system may then be energised, and data loggers installed to monitor the time dependent variation of d.c. pipe to soil potential and current density. Data logging should be carried out at 1 to 2 second intervals.

Post energisation of the HVDC system a CIP survey should be conducted to confirm that any stray current interference is within manageable limits.

8.7.6 Long term monitoring HVDC systems

It would be important to continue using data loggers at periodic intervals to monitor the time dependent variation of pipe to soil at test facilities within the vicinity of the HVDC converter station to provide confidence that the longer-term levels of interference are within acceptable limits.

Consideration should also be given to the installation of a remote monitoring device to provide an indication of an alarm situation on the pipeline in the vicinity of the HVDC system.

It will be important on HVDC systems that the pipeline operator has an agreement in place to cover work on the pipeline and possible interference scenarios. The HVDC system operator and pipeline operator should have an agreement in place to enable data to be shared and any situation that may have caused a significant interference to a pipeline to be identified e.g. short periods when the HVDC system may have operated in monopolar mode or when there have been short circuit events.

Pipeline operators will need to monitor the risk of stray current interference from any HVDC system for the remainder of the pipeline life as it will be a long-term risk.

8.8 Telluric Interference

It has been known for a number of years that geomagnetic field variations associated with ionospheric currents or solar sunspot activity can establish large scale electrical currents in the earth's crust by a process of electromagnetic induction. The pattern of this current flow can be quite complex due to the relatively wide variation in the electrical conductivities of the different materials within the Earth's crust and the high contrast in conductivity between the land and sea.

The stray currents in the earth caused by geomagnetic variations are termed "telluric currents" and they are said to be common between the regions close to the North and South Poles. This is due to the fact that charged particles from solar activity can penetrate the Earth's magnetosphere more deeply at high altitudes where the magnetic field lines are nearly vertical. BS EN ISO 21857 [1] gives good guidance on Telluric interference and should be consulted for additional information.

D.H. Boteler and L. Trichtchenko [43] have also written a section in a textbook on the topic and that provides useful background information on telluric interference on pipelines.

It is understood that telluric currents have been recorded on pipelines close to the equator in the past. They generally occur on pipelines with a relatively long length and close to the poles running in a North-South direction. Telluric currents have been known to cause stray current interference on pipelines in the past. However, Telluric currents are sometimes stated as being the cause of stray current interference when there is no other explanation to account for the stray current phenomenon that was observed.

In order to confirm the existence of telluric currents it is essential that all other possible sources of stray current interference are investigated to eliminate these sources, to ensure that the only possible source of stray current interference is telluric currents.

If the pipeline is subjected to telluric interference it could be a cause for concern particularly if the minimum pipeline protective potential is not maintained and there is current discharge from the pipeline at coating defects. If the source of current flow in the pipeline is telluric currents the magnitude and direction of the current flow would be expected to vary. It is possible to measure current flow on cross country pipelines only if suitable monitoring facilities are present.

Geomagnetic field variations induce telluric electric field in the Earth and in pipelines. The telluric electric field is greater in areas with higher resistivity. The electric fields are also amplified on the more resistive side of a resistivity boundary. This can occur between two geologic zones that have different resistivities (e.g. granites and sediment).

This is most significant at the coast with contrast between the resistive land and the much more conductive seawater. It should be noted that telluric currents have historically not been an issue on most onshore pipeline systems in the UK.

8.9 D.C. Operated UPS and Instrumentation Systems

D.C. operated UPS and d.c. instrumentation systems can cause periodic stray current interference on pipelines especially if positive grounding is employed. Such interference would be exhibited by short duration pules in pipe to soil potential evident on routine monitoring surveys.

The interference can occur where there are grounding electrodes located close to a pipeline with +48V instrument circuits. It is generally not detrimental due to the low current levels.

8.10 New Security Fences for AGIs

To protect existing AGIs from an increased security threat particularly at critical gas and oil transmission distribution sites plus compressor stations a new security fence is often proposed around the peripherals of the site and a new CCTV and electrified fences installed. The new security fence may often be a double fence arrangement with an inner and outer fence as seen on Figure 15.

There is generally a significant amount of reinforcing included as part of any new fence arrangement and if the fence is earthed and connected to an AGI earth, which may also be connected to the buried pipework. Then the new fence may drain a significant level of d.c. current off the AGI CP system.

Where incoming pipelines cross underneath new fences there can be a stray current interference effect on existing pipelines from the current flow to any new fence reinforcing installed close to any incoming pipeline.

Prior to any new security fence installations, the possible effects on pipeline CP systems should be considered. This would include the status of existing CP systems, locations of existing groundbeds and possible site surveys

Electrified fences are also d.c. operated systems but because they provide low levels of leakage current, they should not create a d.c. stray current interference effect. Nevertheless, it is still recommended that data logging of pipe to soil potentials is carried out before and after energisation.

Figure 15 Typical New Security fence under construction

Localised depression of the CP level on the incoming pipelines can occur in such a situation. as is evident from a CIP plot of an installation where such problems have been experienced (see Figure 16)

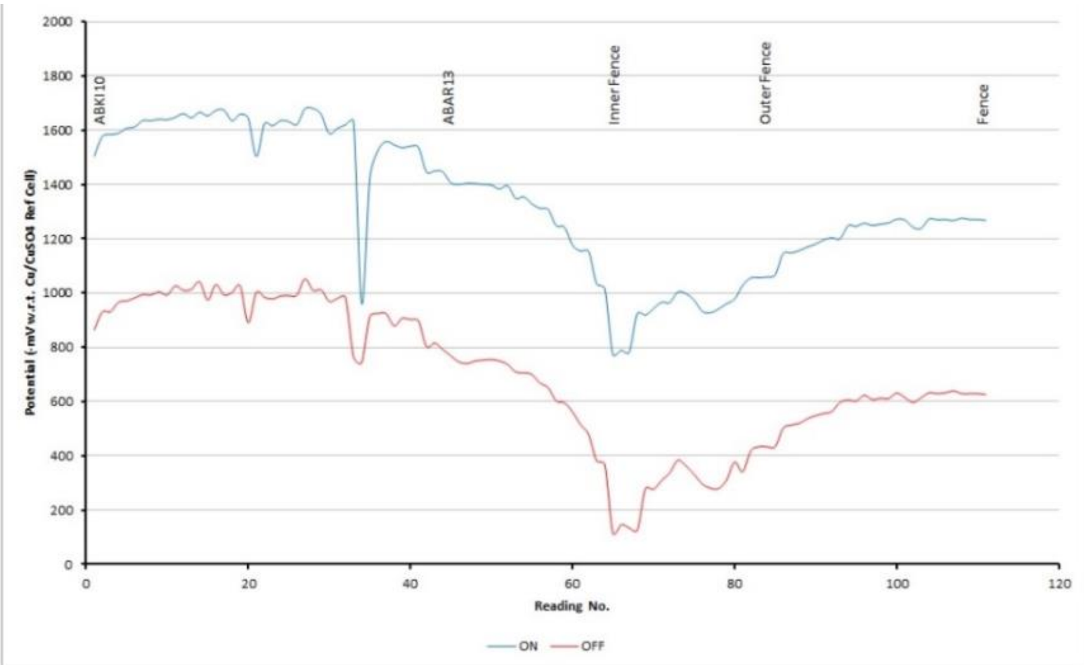

Figure 16 CIP plot on Incoming Pipeline After New Reinforced Concrete Security Fence Foundation installed

Prior to any new security fence installations, the possible effects on pipeline CP systems should be considered. This would include the status of existing CP systems, locations of existing groundbeds and require site surveys to establish the CP status on pipelines prior to any construction activities.

It would be advisable to conduct CIP surveys on pipeline systems affected by any new fence installation before and after fence installation to confirm that there is no detrimental effect on a pipeline system.

8.11 Mitigation of Interference

Where routine monitoring indicates an unacceptable level of stray current interference, the operator of the d.c. system causing any interference should be contacted in the first instance.

The pipeline operators CP specialist or technical authority should be contacted to determine what action to take to mitigate any interference.

Sacrificial anodes may be used at sites of anodic interference to allow stray current to flow from the pipeline back to earth. However, where sacrificial anodes are employed their location should be noted on drawings as they will need to be switched when any CIP surveys are conducted in the future.

Schottky diodes can be installed in anode circuits to ensure that current flow is in one direction only and that anodes do not act as collection points for stray current interference current. Thus, anodes with diodes installed will permit current flow only in one direction. The diode voltage should be selected so as to minimise the reduction in sacrificial anode driving voltage.

A Schottky diode is a diode that has a lower p-n junction voltage than a conventional diode. The forward voltage or voltage required before any current can flow in a conventional diode is in the region of 0.5 to 0.7V. In the case of a Schottky diode or Schottky barrier rectifier the forward voltage is considerably lower and is typically in the range 0.15 to 0.4V.

It should be noted that the diode forward voltage is dependent upon the current magnitude flowing in the diode and the anticipated current flow in terms of mA through the diode should be considered to select the likely decrease in sacrificial anode driving voltage.

Designers should consult the voltage vs current curves for a particular Schottky diode to assess its suitability for a given application see Figure 17. Sacrificial anodes act as not only current discharge locations but current collection sites as well and the use of diodes will prevent anodes acting as collection points for stray current. Stray current collected on a pipeline can discharge at other locations possibly leading to corrosion.

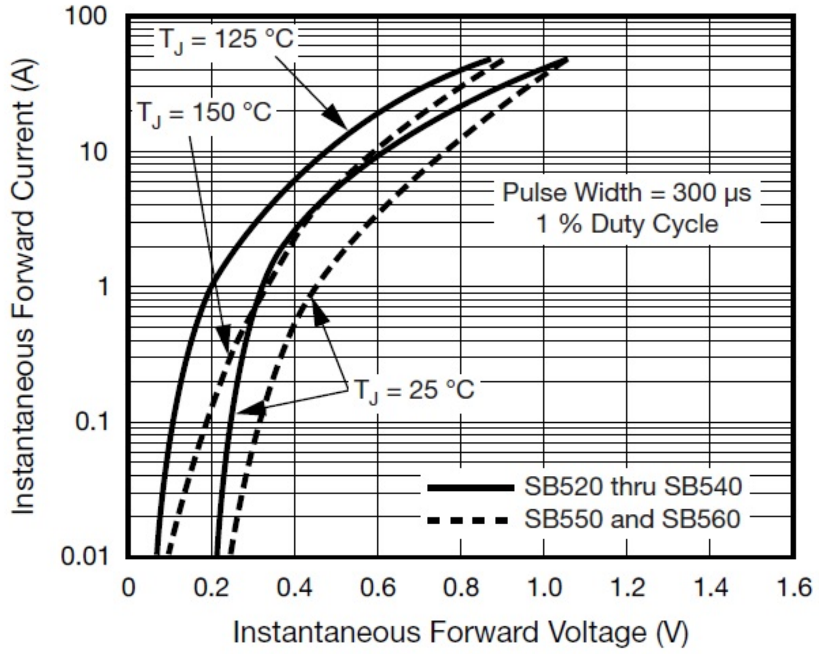

Figure 17 Typical Diode Instantaneous Forward Characteristics

One limitation of Schottky diodes is their relatively low peak inverse or reverse voltage ratings, and their relatively high reverse leakage current. For silicon-metal Schottky diodes, the reverse voltage is typically 50 V or less. Some higher-voltage designs are available (200 V is considered a high reverse voltage).

When installed between a sacrificial anode and pipe connection if the anode voltage is -1,750mV vs $Cu/CuSO_4$ and the Schottky diode voltage at the required current is 400mV then the effective anode driving voltage would be 1,350mV and the magnitude of reduction in anode driving voltage should be considered in the CP system design, should a Schottky diode connection be made. Increase in current flow through the diode will increase the required forward voltage. The use of Schottky diodes should only be considered if there are significant levels of interference.

More frequent monitoring will be required in situations where diodes are installed as they may fail open circuit, which could lead to loss of CP.

8.12 Potential Controlled T/R Units

Cathodic protection systems may utilise automatic potential-controlled transformer rectifiers where there is a stray current interference risk. These T/Rs use a permanent buried reference electrode to sense the pipe to soil potential and attempt to maintain a set pipe to soil potential despite potential excursions arising from stray current interference.

Thus, if a T/R unit is set to maintain a drain point potential of -1,500mV vs $Cu/CuSO_4$ it will only provide current if the pipe to soil potential becomes less negative than the set point to maintain the desired drain point potential.

These systems are sensitive to the location of the permanent reference electrode and to the reaction time of the T/R units to potential excursions. Where potential controlled T/R units are employed on long pipeline systems it should be noted that if the pipe to soil potential at a given T/R location exceeds the set potential i.e. it is more negative than the control potential on the T/R unit then the T/R unit will not provide current output. This would mean that the pipe to soil potential on sections of a pipeline remote from any T/R unit could be reduced and may even fall below the required minimum protection criterion.

This possibility of not achieving the required protection criteria at all times on a pipeline system should be taken into consideration when any potential controlled T/R units are intended to be used on pipeline systems. In addition where employed potential controlled T/R units should have the ability to work in constant current mode as well in case subsequent monitoring reveals that the potential control system does not ensure that all sections of the pipeline system attain the desired structure to soil potential criterion or a T/R unit cannot respond in time to the potential excursions that are experienced. The locations where low pipe to soil potentials could be recorded would be at mid points between T/R units and data loggers should be placed at representative test facilities along a pipeline route to ensure that even when T/Rs are operating in constant potential mode that the required protection criteria are always maintained along the entire pipeline system.

If potential controlled T/R units are installed it is often not possible to carry out CIP surveys with T/R units set to constant potential mode, as during the switching cycle current spikes will be evident. In such conditions the T/R units should be capable of providing a smooth current output when switched and no sharp spikes in current. T/R units should also be capable of being operated in constant current mode for the purposes of conducting a CIP survey. Mobile CIP data loggers should be capable of adjustment to read both ON and OFF potentials at set periods of time after the switching cycle so that voltage spikes can be discounted from data.

8.13 Installation of DC Mitigation and Monitoring Systems

Once a pipeline system is installed it is important to obtain base line date on the levels of d.c. interference levels that exist on a pipeline prior to installation of any d.c. interference mitigation system e.g. unidirectional bonds.

It is important that any interference monitoring and mitigation system design includes for suitable test facilities to monitor interference levels.

The designer should consider whether there is a requirement for the installation of ER probes or similar devices to monitor corrosion rate as part of the design process. It is essential that coupons are installed with a surface area of 1cm^2 and a permanent reference electrode.

Where employed, coupons should be designed so that they can be removed for subsequent laboratory examination at a later date and the date of coupon installation should be accurately recorded.

Coupons if complete with factory connected cable can be excavated and removed for inspection at some time in the future and sent to a test laboratory for metallurgical examination (see Appendix G). This will provide an indication as to whether or not corrosion has been on going and the possible extent.

Guidance on the use of coupons for CP monitoring purposes is given in ISO/FDIS 22426 - Assessment of the effectiveness of cathodic protection based on- coupon measurements [44]

8.14 Remote Monitoring

On new pipelines where a d.c. interference risk has been identified, then at least one remote monitoring device should be employed and installed at a high-risk location. The designer may select additional remote monitoring locations once the detailed design has been completed or an assessment of the interference risk has been conducted.

It should be noted that the accuracy of remote monitors should be confirmed at the time of installation and checked at periodic intervals typically once every 3 years thereafter.

Consideration should also be given to the use of remote monitoring devices on existing pipelines where there is a known d.c. interference risk. The remote monitoring device should monitor the a.c. and d.c. current densities, a.c. pipe to soil potential and d.c. pipe to soil potential.

The remote monitor should be of a proven design and record values at the time of day when the maximum levels of interference are likely to be present on a pipeline. The devices should report to a central data base and be able to provide an alarm indication.

The alarm levels should be selected by the Operator at the time of installation and be set to values that will represent a level that would need action e.g. where acceptable levels of ON pipe to soil potential are not achieved or there is positive d.c. current discharge through coupons.

Remote monitoring devices should also be installed at critical bond locations

8.15 Commissioning

It is important that following installation of a d.c. interference. monitoring and mitigation system that all necessary pre-commissioning checks are conducted. The mitigation system should be commissioned to confirm it meets with the design specification and a fully detailed commissioning report produced.

The following tests should be performed at CP monitoring locations as part of the commissioning checks.

- a.c. pipe to soil potential
- d.c. pipe to soil potential 'ON'/'OFF'
- a.c. current density
- d.c. current density
- Coupon instant 'OFF' potential
- T/R unit output levels
- d.c. current flow though bonds

All measurements should be performed with calibrated test equipment capable of measuring true rms values in the case of a.c. voltage readings.

A.C. and d.c. current density readings should be taken on all coupons.

Data logging should be performed to determine the time dependent variation in both a.c. and d.c. pipe to soil potential and current density. The data logging should be performed prior to and after energisation of any d.c. power system.

Electrical performance tests shall be carried out on any a.c. operated equipment installed as part of a stray current mitigation system e.g. on potential controlled T/R units and forced drainage bonds.

8.16 Documentation

Any detailed design for a d.c. interference mitigation and monitoring system should include a detailed specification for all materials and identify the commissioning requirements.

Detailed as built records should be provided and all documentation updated to as built status following construction and commissioning. Manufacturer data records should be provided for all material incorporated into any CP system and mitigation system and a fully detailed commissioning report provided. An Operations and Maintenance manual should also be provided for any new schemes.

8.17 Specialist Problems

If there are issues of concern associated with the operation of d.c. stray current interference mitigation and monitoring systems then, the advice of a corrosion engineer specialising in d.c. stray current interference effects may be required.

9. MONITORING REQUIREMENTS D.C. INTERFERENCE

9.1 Stray Current Monitoring and Assessment

Pipeline systems susceptible to d.c. stray current interference should be identified by pipeline operators and high-risk locations on a pipeline system should be determined e.g. pipeline crossings of d.c. traction circuits or pipelines routed close to HVDC substations. Pipelines should be classified in terms of risk due to stray current interference with relevant factors taken into consideration namely pipeline age, wall thickness, operating pressure, whether inspectable or non-inspectable and protection criteria achieved.

CP test facilities on pipelines affected by stray current interference should contain as a minimum a 1cm^2 exposed surface area coupon and a suitable permanent buried reference electrode positioned as described in Section 10.2. On existing pipelines if only a 10cm^2 coupon is installed then that too can be used for stray current interference assessments.

A pipe connection to the pipeline under test is required of minimum conductor size 10mm^2. The pipe cable colour should conform to the pipeline operator's local area requirements. Suitable designation in terms of cable colour should be provided to indicate whether any coupon has a 1cm^2 or 10 cm^2 exposed surface area.

The magnitude of the coupon current density and the period of time that anodic current discharge occurs for can be used to assess the corrosion risk on a pipeline system (see Sections 5.6 and 5.7)

A suitable data logger is required to monitor the time dependent variation of d.c. current density over time to provide information on the levels of interference. The data logger should be capable of providing data in an Excel format for subsequent analysis and be suitable for use on pipelines affected by both d.c. and a.c. interference levels. The surface area of new coupons should be clean and free of grease or surface contamination before installation. Coupons should be installed so that the exposed coupon surface area is pointing away from the pipeline and the coupon is bedded into graded local soil. The coupon spread resistance should be checked after installation and should ideally be less than 1 Ohm m^{-2}. It important to check that a coupon is correctly installed before completing all the backfill operations and re-instatement.

9.2 Reference Electrode and Coupon Location

BS EN ISO 21857 [1] advises that the reference electrode should be placed in the following locations.

- At pipeline crossings of railway lines, a reference electrode should be placed above the pipeline with a distance to the outer rail that corresponds to the smallest distance between rail and pipeline.

Where pipelines are parallel to a railway reference electrode should be placed above the pipeline.

Where pipelines are installed within the gradient of a groundbed reference electrode should be placed above the pipeline at the location with the smallest distance between pipeline and anode.

There are cases where it is not possible to place the reference electrode, coupon or probe at the relevant locations described above. The expected level of interference at the relevant position should then be extrapolated based on the electrical field distribution to the position with the smallest distance between pipeline and the stray current interference source.

9.3 CIP Surveys

On pipelines susceptible to stray current interference it is difficult to carry out accurate ON/OFF CIP surveys, as the ON pipe to soil potentials will be fluctuating during the survey because it is not possible to interrupt all current flowing to a pipeline system. The OFF potential will not be a true instant OFF potential, as once the CP current source is switched there may be current from the interference source affecting the pipeline and either entering or leaving the pipeline.

On pipelines that have potential controlled transformer rectifiers to manage stray current interference it is generally not possible to carry out CIP surveys with the T/R units set to constant potential control and any CIP surveys should preferable be carried out with the T/R units set to constant current mode. The time after switching and re-energising the CP current source when ON and OFF potentials are recorded should be delayed after the current source is switched and set so that potential spikes caused by switching are not recorded. This can be confirmed with the aid of an oscilloscope.

On pipelines subject to stray current interference it is essential that a static logger is employed in addition to the mobile CIP data logger. The static logger should be positioned within 3 km of the mobile logger.

If a new d.c. traction system or HVDC cable system is to be employed then it is important to conduct a CIP survey along the entire length of any affected pipeline prior to energisation of the traction system or the HVDC power system to obtain accurate baseline survey data. Baseline surveys are important as once the d.c. stray current sources are energised it may not be possible to carry out accurate CIP surveys in future due to stray current. Consideration should be given to performing CIP surveys when the interference source current is lower or not present.

CIP survey plots are useful as they can be used to identify possible stray current interference locations along a pipeline route e.g. at third party pipeline crossings or other locations where current discharge may be occurring.

9.4 Coating Defect Surveys

On pipelines susceptible to stray current interference it is difficult to carry out accurate ACVG or DCVG surveys as it is not possible to interrupt all sources of d.c. current flowing to the pipeline system during the survey.

If specific features are to be located e.g. those identified from ILI runs or from CIP survey data, then consideration should be given to performing CIP and coating defect surveys when the interference source current is reduced or not present, which in the case of d.c. traction interference would be at night time.

There is still considered to be a benefit from conducting ACVG or DCVG surveys when there is stray current present, but caution should be exercised when interpreting data.

If a new d.c. traction system or HVDC cable system is to be constructed then it is important to conduct a coating defect survey along the entire length of any affected pipeline prior to energisation of the traction system or the HVDC system to obtain a baseline survey data and pin point all coating defects even those with a small % IR value. All coating defects no matter how small should be located and recorded to a high level of accuracy in case they need to be exposed at some stage in the future.

Where possible benchmarking should be conducted using any permanent coupons already installed or if no permanent coupons are available the use of temporary coupons should be considered.

9.5 Data Logging

On pipelines susceptible to d.c. stray current interference at selected test facilities and at all rail bonds data logging should be performed at periodic intervals throughout the life of the pipeline. Data logging of high-risk CP posts to establish the time dependent variation in pipe to soil variation should be undertaken at periodic intervals to confirm that the protection levels meet the required limits

In the case of d.c. stray current interference data logging measurements should include d.c. pipe to soil potential ON and OFF potential measurements and d.c. current measurements through coupons.

For d.c. stray current interference monitoring operators should have data loggers that can undertake frequent sampling at rates in the range 0.1 to 5 seconds. The data loggers should have a minimum input impedance of at least 10MΩ.

The magnitude and direction of the current flow should also be able to be recorded using shunts with a maximum resistance of 10 Ohms.

Section 7.3 of BS EN ISO 21857 [1] should be consulted for guidance on data measurement requirements and techniques.

9.6 Frequency of Testing

Pipelines that are at risk of d.c. interference can suffer higher rates of corrosion than those not exposed to a d.c. stray current interference risk

The inspection frequencies detailed in any maintenance procedures for cathodic protection typically apply to pipelines that are not subjected to either a.c. or d.c. interference. However, since stray current interference can result in higher rates of failure on pipelines than those not at risk then more frequent inspection intervals may be required on pipelines susceptible to d.c. interference.

If the OFF pipe to soil potential levels on a pipeline system fall below the operator's minimum criterion then there may be a higher risk of accelerated corrosion and the inspection frequencies for pipelines susceptible to interference may need to be amended.

Where data loggers are employed to determine levels of stray current interference the sampling should take place over a minimum period of 24 hours and at a time where the highest and lowest levels of interference are expected.

An assessment of the level of stray current corrosion risk on different pipeline systems should be carried out to determine the inspection frequency that will apply to a specific pipeline. If a pipeline system is exposed to significant levels of d.c. stray current interference, then it may be necessary to review the inline inspection interval as well and increase the frequency at which inline inspection is carried out.

9.7 In-Line Inspection

Appendix G of this GPG provides guidance on the use of inspection vehicles to detect external corrosion features on pipelines susceptible to d.c. stray current interference

10. INTERNAL CORROSION RISK AT I/JS FROM D.C. STRAY CURRENT

10.1 Introduction

On cathodically protected pipelines that contain a conductive liquid, corrosion can occur on the non cathodically protected side or the least cathodically protected side of an I/J or I/F due to stray d.c. current. In addition, if there are high resistance joints in cathodically protected pipelines containing conductive fluids, there may also be a risk of internal corrosion due to stray current in such situations.

It is important that pipeline operators are aware of the internal corrosion risk on cathodically protected pipelines and identify locations where there could be an internal corrosion risk due to d.c. stray current interference and take appropriate action to mitigate and monitor the risk. The monitoring should take the form of enhanced NDT checks on the non cathodically pipework close to an I/J or I/F. The NDT checks would include checks for reduction on pipe wall thickness and may include radiography, UT or MPAUT techniques that are approved by the operator.

For the design of new pipeline systems where there may be an anticipated internal corrosion risk from d.c. stray current then the use of insulating spools should be considered as described in the guidance given in Section 10.3 and BS EN ISO 15589-1 [34].

Internal corrosion on the non cathodically protected side of an I/J or I/F from stray current is not uncommon and there have been a number of instances where corrosion has taken place on the unprotected side of I/Js containing a conductive fluid. This can lead to loss of containment.

Figure 18 shows an example of a location where corrosion has occurred on a multi-product line. Figure 19 [34] provides a view of a pipe failure due to internal stray current corrosion. Corrosion failures can occur on not just mild steel pipelines, but pipelines constructed from CRAs under certain conditions.

Figure 18 View of Pipeline System Subjected to Internal Corrosion

Figure 19 View of Pipeline System Subjected to Internal Corrosion Due to Stray Current

There is guidance given on the risk of internal corrosion on cathodically protected pipelines in different corporate and international standards e.g. BS EN ISO 15589-1 [34].

10.2 Corrosion Mechanism

The mechanism whereby internal corrosion on pipelines at I/Js can occur due to d.c. stray current is shown in Figure 20. The cause of internal corrosion in such instances is well understood and accelerated corrosion is not an unforeseen problem, where there is a conductive liquid present within a pipeline system that is under cathodic protection.

Figure 20 shows the stray current corrosion process. The internal surfaces on the non-protected side of an isolation joint or insulated flange can act as an anodic site. The non-cathodically protected side of an I/J or I/F will have a less electronegative potential than the cathodically protected side of the I/J. This will result in a positive potential difference across an I/J or I/F and the voltage difference is the driving force for the internal corrosion process.

The current then flows from the anodic sites to the cathodically protected side of the I/J. The cathodically protected side of an I/J acts as the internal cathodic site and the current will return back to the d.c. power source.

The magnitude of the current flow within an I/J depends upon water composition of the fluid being transported, the liquid conductivity, liquid temperature and the anodic polarisation characteristics of the pipe material in the water phase that it is exposed to.

The exposed surface area of steel or CRA at any coating damage on any pipe internal coating systems is an important factor, as is the temperature of the corrosive liquid. If the surface area that is exposed is low, then the anodic current density at any coating defect may be relatively high, and this can result in a high localised pitting/corrosion rate.

The corrosion rate will generally be proportional to the anodic current density at the stray current discharge location.

For stray current interference to occur there needs to be a conductive product present within an insulation device and the conductive product length needs to extend between the unprotected electrical section connected to an insulating device and the cathodically protected section. The nature of the electrolyte present is important since the electrolyte would need to have a water phase composition that will enable the breakdown of the protective oxide film on the steel or even any corrosion resistant alloy surface. The conductivity of the water phase within an I/J is an important factor with the higher the conductivity, the greater the magnitude of current flow for a given driving voltage

It is sometimes preferable to have no coating on the non cathodically protected side of an I/J to reduce the effective anodic current density but also to have a higher quality coating on the cathodically protected side of an I/J to reduce the cathodic current. The requirements for internal coating of I/Js should be considered as part of the design process.

There needs to be a potential difference across the I/J or I/F for the internal corrosion process to proceed. The greater the potential difference the greater the magnitude of current flow and hence the internal corrosion rate.

If the I/J internal surface is coated, there will only be current flow from the exposed sections of the steel I/J. Thus, the internal coating quality is also an important factor. If the coating was 100% defect free, then no current would be able to leave the steel surface. The situation is clearly relatively complex on the internal surfaces of the I/J.

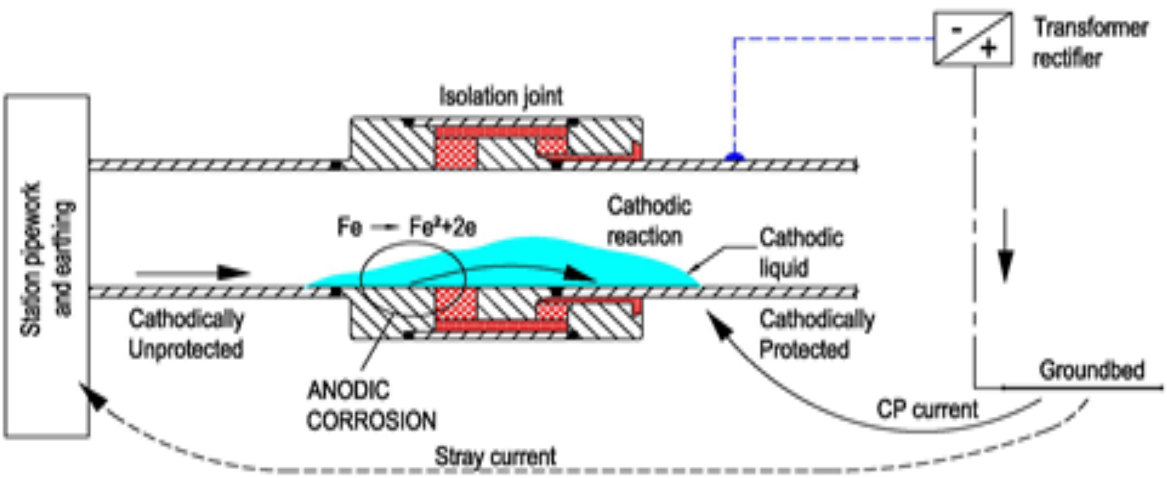

Figure 20 Schematic Representation of Internal Corrosion Stray Current Corrosion Mechanism

10.3 BS EN ISO 15589-1 Guidance

BS EN ISO 15589-1 [34] advises in relation to the risk of internal corrosion at I/Js or I/Fs on pipelines carrying conductive liquids.

"In pipelines carrying fluids with a separate water phase, there is a risk of internal corrosion caused by current leaving the internal surface of the pipe close to the isolating joint on the side that has a less negative internal potential (anodic side). This is mainly dependent on the conductivity of the fluid and the voltage between both sides of the isolating joint. To prevent or mitigate this internal corrosion risk, a lining (internal coating with an electrically isolating material) should be applied on the side of the pipeline with the more negative internal potential.

The length of the section being lined internally increases with increasing electrolyte conductivity, increasing pipeline diameter and increasing voltage on the sides of the isolating joint. If there is no prior knowledge from previous experience, then the length of pipeline being lined should be determined by calculations or tests.

The length of internal coating can be determined by defining an internal ohmic resistance of the internal fluid. This assessment can be made using simulation software or by calculation (Ohm's law) and shall be documented. This study shall be made considering the fluid resistivity, the potential drop between each part of the isolating joint, and the absence of external coating defect on the anodic side of the pipeline.

> *NOTE 1 Based on feedback and experience, a value of 100 Ω for the internal ohmic resistance is commonly used for the evaluation of the length of the internal coating.*
>
> *NOTE 2 For long lengths of lining, an entire pipe length lined in a factory is generally used. In practice, if both sides of isolating joints are lined, the length of the lining on the cathodic side shall be at least the calculated length.*
>
> *NOTE 3 When custom made asymmetrical lined isolating joints are used, the risk incurred by installing the longer liner on the wrong side of the isolating joints can be significant. The lining should be of a type that does not deteriorate when in contact with the internal fluid, especially in the case of a lining exposed to saltwater. An alternative to internal lining is to install a sacrificial steel pipe spool piece next to the isolating joint"*

Shell [40]. *advise "that to avoid internal corrosion the following guideline applies: If the resistivity of the electrolyte is higher than 100 Ω.cm, or the volume occupied by the electrolyte is less than 5 % of the pipeline volume, the overall length of the isolating joint shall be four times the pipe diameter with a minimum of 1 m. If the resistivity of the electrolyte is below 100 Ω.cm and the volume of electrolyte is more than 5 % of the pipeline volume, isolating spools shall be used. The length of an isolating spool shall be determined by the following formula:*

$$L = (400 / \rho) \times D$$

where: L = length of spool (cm).

ρ = electrolyte resistivity (Ω.cm).

D = nominal pipe diameter (cm).

.

10.4 Measures to Reduce the Risk of Internal Corrosion

It is often not possible to retrofit isolating spools in pipe assemblies to reduce the internal corrosion risk. Thus, it is important at the design stage to identify locations where there could be an internal corrosion risk and ensure that isolation spools are correctly designed and installed at the time of construction.

The rate of internal corrosion is dependent upon the voltage difference across an I/J. Thus, limiting the voltage difference across an I/J would be one method of controlling the stray current interference risk. This can be achieved by reducing the level of protection afforded to the cathodically protected side of the I/J or conversely increase in the level of protection afforded afford to the pipeline/pipe system on the Dead side of an I/J..

There are several methods that could be applied to reduce the extent of stray current interference on isolation joints where there is a conductive fluid. The advantages and disadvantages of the various options have been summarized in Table D1 in Appendix D of this report. If a resistive bond was used, then whilst the two sides of an I/J will be bonded there will still exist a potential difference across the I/J. The magnitude of the potential difference is dependent upon bond resistor value and current flow.

The potential difference across any I/F or I/J needs to be reduced to as low a value as possible to minimise the internal corrosion risk. It would also be important to ensure that any resistive bond is located outside a hazardous area. This is because resistors would only be able to be installed in hazardous areas in EExd certified enclosures. If installed in an EExd enclosure this would mean adjustment and balancing of resistor settings would be extremely difficult.

A risk ranking evaluation should be carried out on pipelines where there is a risk of d.c. stray current corrosion on the internal surfaces. Each respective I/J should be looked at on a case by case basis to determine the level of risk. All relevant data should be collated, and an RBI interval and inspection regime adopted. The following data would be of benefit in assessing the risk:

Water composition, temperature, and product data within each line

a) CP operating data including potential difference across IJs

b) I/J installation date and pipe wall thickness

c) Pipeline/flow line operating data

d) Information on I/J failures e.g. location, reports etc.

e) Does an I/J have an internal coating?

Pipeline operators would need to develop an inspection regime to monitor the corrosion risk, measure stray current currents and interference levels. It may even be necessary to undertake period examination of the internal surfaces of some I/Js.

The ability of different inspection techniques to identify localised pitting should be assessed. The orientation of the I/J should be considered i.e. whether orientation in a vertical plane would be of benefit and prevent water accumulation across the I/J. If horizontal and there is water phase drop out during stagnant flow conditions, then conductive product would be present on the bottom of the I/J.

11. CURRENT FLOW IN PIPELINES

11.1 Introduction

D.C. current flow in pipelines can affect pipeline instrumentation systems and can also result in an incendive ignition risk associated with disconnection or cutting of pipelines or earth conductors connected to pipelines which carry d.c. or a.c. current.

The safety aspects of working on pipelines where either d.c. or a.c. current may flow are discussed in UKOPA/TBN/005 [7].

D.C current flow in pipelines is typically associated with current from pipeline CP systems but on pipelines subjected to d.c. stray current interference significant levels of d.c. current can also flow e.g. on pipelines where there are uni-directional rail bonds installed, there is d.c. stray current interference or from bonds with adjacent pipeline CP systems.

Thus, isolation of a pipeline CP system alone may not remove all sources of either d.c. or a.c. current flow. This needs to be taken into consideration where disconnection of pipelines or current carrying conductors could result in an incendive ignition risk.

11.2 Flow Meters

The effect of d.c. and a.c current flow in pipelines on certain instrumentation systems is detailed in Section 7.1.4.3 of ISO 6817 [45] and BS 6739 [46]. When an electromagnetically operated flow meter device is installed in a cathodically protected pipeline special precautions are necessary to ensure that the d.c. current associated with the pipeline cathodic protection system does not affect the accuracy and stability of the flowmeter system.

In such cases the flowmeter manufacturer should be consulted for installation advice in relation to the effects of d.c. and also a.c current flow in pipe systems. The precautions required will be dependent upon the primary device relative to other parts of the CP system. The precautions would typically include the installation of insulation devices each side of the flow meter to prevent d.c. current flow through the flow meter, which may affect the meter accuracy.

Where flow meters are installed on cathodically protected pipelines then the effect d.c. current flow can have on the measurement values obtained should be confirmed with the meter manufacturers.

BS 6739 [46] does give guidance on the effect of CP current on measurements by electromagnetic flow meters and states:

" If the detector head is installed in a system that is cathodically protected or where electrolysis is used in the process, special precautions should be taken to ensure that: current at supply frequency does not flow through the liquid in a) the detector head; any current, at supply frequency, flowing through the body of the b) detector head does not exceed 10A r.m.s. these precautions are intended to limit the magnitude of any spurious magnetic fields.

In systems where a metal pipeline without an insulating liner is used, the liquid in the system can be placed at earth potential by bonding the detector head to the adjacent pipeline as shown in Figure 12a) in BS 6739. This arrangement should only be used for systems where it is known that any current flowing through the body of the detector head does not exceed 10A r.m.s. if the current flowing through the body of the detector head exceeds 10A r.m.s., The detector head should be bonded to the adjacent pipeline as shown in Figure 12b).

When bonding the detector head flanges, flange bolts should not be relied upon as electrical connectors. troublesome potential differences can occur in systems where, for example, a cathodically protected pipeline joins a grid system, not quite at earth potential, or joins an earthed pumping station. in these cases, it might be necessary to insert short lengths of unlined pipework bonded to the detector head as shown in Figure 12c)" .(see Figure 21 in this GPG*)*

The length of these sections will depend upon the magnitude and ripple content of the cathodic voltage and upon the nominal bore of the pipeline.

The guidance in BS 6739 [46] is not particularly clear as it refers to r.m.s current and not current from a d.c. system such as a CP TR unit. The r.m.s current on the d.c. current from a CP system T/R unit should be limited. For a CP T/R unit provided with a single phase 230V input with no smoothing on the d.c. output the a.c r.m.s current would only be in the region of 22% of the T/R unit d.c. output current and is unlikely to approach the 10A stated in BS 6739 [46].

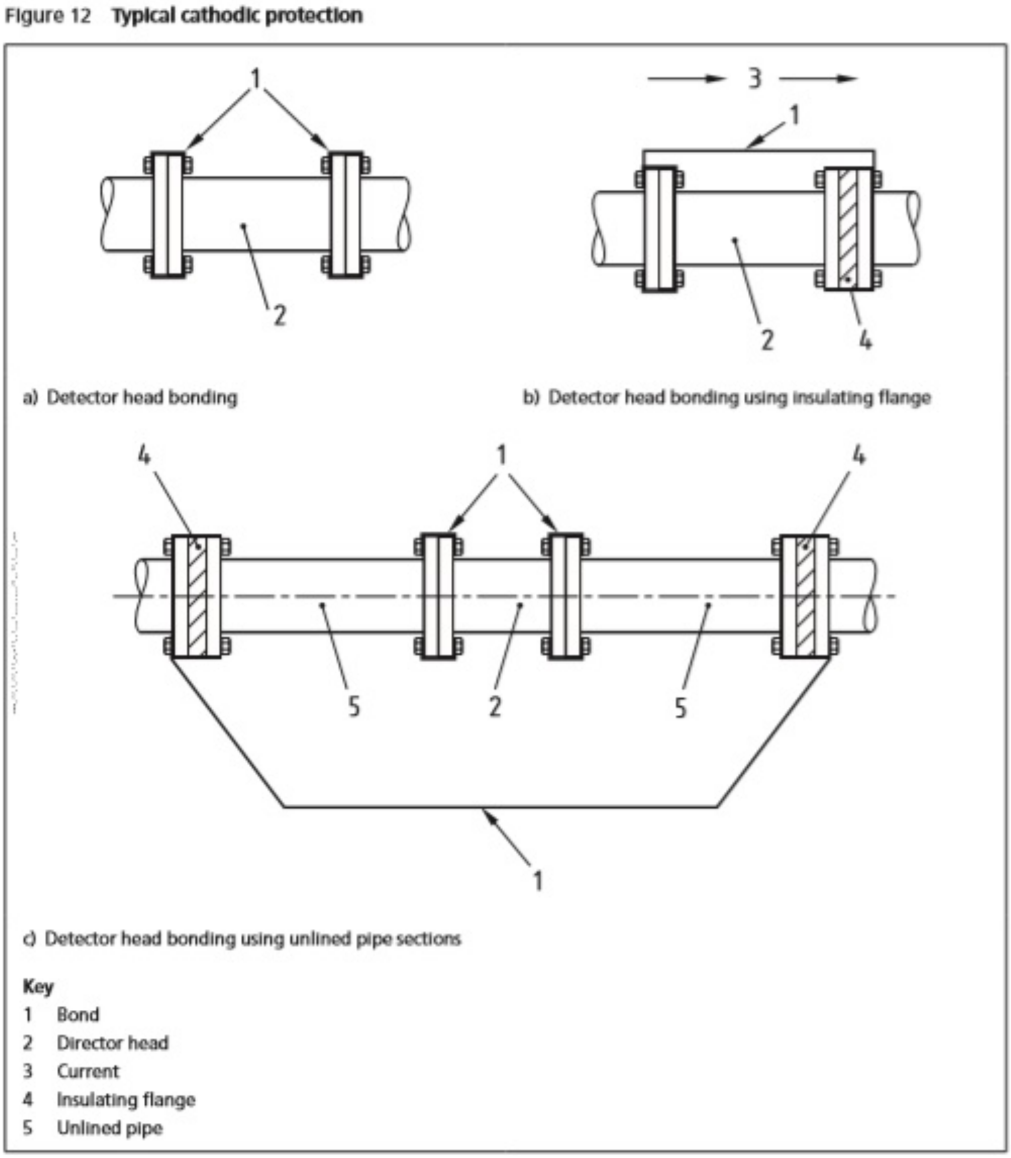

Figure 21 Schematic Representation of Electrical Isolation Requirements Defined in BS 6739 for Electromagnetic flow Meters

11.3 Electrical and Incendive Ignition Risks from CP Current

The application of cathodic protection within plant areas can cause an increase in the resistance of earth electrodes within a plant, particularly where there is a high d.c. current flow to earth. This increase in resistance to remote earth is caused by the build-up of a high resistance calcareous film on earthing electrodes (calcareous deposit). The higher the CP current the greater the extent of deposit formation.

The resistance to remote earth of earthing electrodes in plants where cathodic protection systems operate should be checked on a regular basis to ensure the earth resistance remains within prescribed limits and is sufficient to ensure protective devices will operate within the required disconnection time.

In cases where the current demand for CP system is considerable there may be d.c. current flow in earth conductors and above ground pipework. Operations personnel need to be aware of this as there may be a potential spark hazard when an earthed conductor or section of pipe work is disconnected. In areas where flammable mixtures of gas are present, these can be ignited by an electric arc or spark.

Unless precautions are taken, cathodic protection systems may introduce the danger of sparks.

Guidance on cathodic protection in hazardous areas is given BS EN 60079-14 [47]. *Section 6.7 which states "Cathodically protected metal parts in hazardous areas are live extraneous conductive parts, which shall be considered as potentially dangerous (especially if equipped with the impressed current method) despite their low negative potential. No CP shall be provided for metallic parts in Zone 0 unless it is specifically designed for this application. The insulating elements required for CP for example insulating elements in pipes and tracks, should if possible be located outside the hazardous area".*

The spark energy is proportional to square on the current flow and thus the higher the current magnitude the greater will be the incendive ignition risk.

12. MONITORING

12.1 Frequency of Monitoring and Nature of Testing

Failure of a CP system would generally not lead to high rates of corrosion on a pipeline in the short term. However, where there are detrimental levels of d.c. interference present on a pipeline then corrosion rates considerably in excess of the free corrosion rate for steel in soil may be experienced.

D.C. interference on cathodically protected pipelines can result in high rates of corrosion, If the levels of d.c. interference are effectively managed the corrosion rate on pipeline systems can effectively approach the levels where there are effective levels of CP, which as stated in BS EN ISO 15589-1 [34] is 0.01mm per year.

An increased frequency of monitoring is recommended for pipelines affected by d.c. interference. This is because if there are significant levels of d.c. interference this can affect the integrity of pipeline systems and can result in corrosion rates considerably in excess of those typically experienced on pipelines with effective levels of CP. In certain circumstances corrosion rates can be in the regions tens of mm per year.

BS EN 50162 [2] advised that "*All plant and equipment which has been installed to limit the flow of stray current into the electrolyte, or to mitigate its effect, should be inspected and maintained at reasonable intervals (see BS EN 12954 for corrosion mitigation systems)". However, this GPG has identified frequencies identified in BS EN 12954 are those on pipelines not susceptible to a d.c. stray current interference risk and on those where there is a d.c. interference risk it is recommended that an increased frequency of monitoring should be considered*."

BS EN ISO 15589-1 [9] includes guidance on cathodic protection monitoring but does not specifically address d.c. interference risks. Thus, monitoring CP systems subjected to d.c. interference at the frequencies identified in BS EN ISO 15589-1 [34] it is considered may not necessarily be sufficient to address the d.c. interference risks on all pipeline systems.

Pipeline operators should determine the inspection frequency for pipelines susceptible to d.c. interference based upon the risks to a particular pipeline and its operational records. The CP system monitoring frequency should be subject to periodic review during the lifetime of a pipeline system, as additional sources of d.c. interference may be present and could affect and enhance the d.c. interference risk.

The guidance in this GPG is that for pipelines susceptible to d.c. interference the monitoring frequency should at a minimum be similar to that given in BS EN ISO 15589-1 [34]. However, pipeline operators should carry out their own assessment of the level of risk to pipelines subjected to d.c. stray current interference with the aim of possibly enhancing the inspection regime and frequency

Table 5 in this GPG provides guidance on recommended inspection frequencies for d.c. mitigation and monitoring systems based upon the guidance in BS EN ISO 15589-1 [34].

D.C. stray interference monitoring should be combined with routine CP system monitoring checks to maximise resources.

It is recommended that for pipelines where a d.c. corrosion risk has been identified that a suitable remote monitoring system should be employed. The remote monitor or monitors should be located at high risk locations to warn of alarm situations i.e. situations where there is a risk of d.c. interference and corrosion e.g. at uni-directional bonds, pipeline crossing locations of d.c. traction systems or close to HVDC cables and converter stations.

It is also recommended that on pipelines susceptible to d.c. interference that data loggers are employed periodically at high risk locations, where the highest levels of d.c. pipe to soil potential changes have been recorded to confirm the time dependent variation in d.c. current density and pipe to soil potential to confirm whether the protection criteria identified in Section 5 are complied with.

The use of data loggers to determine the time dependent variation in d.c. current density and pipe to soil potential at high risk locations should be considered at periodic intervals.

If a d.c. voltage or current density reading is only taken once every 6 months at CP test facilities or on some pipeline systems where a major CP inspection is performed once every 5 years at all CP test facilities the latter inspection frequency would be insufficient to identify any significant d.c. interference risks.

Data logging where employed should take place over a representative period of time e.g. at least 24 hours to provide valid data. In the case of d.c. traction system interference data logging it should be carried out during a weekday, when the train operating frequency would be at its highest.

Nature of Test	Monitoring Frequency
Reference electrode calibration	1 to 3 years
Uni directional bonds/diode checks	Once per month
CP test station a.c. /d.c. potential measurements ‘ON’/’OFF’	Every 6 months
A.C./D.C. current density measurements at a.c./d.c. coupons	Every 6 months
‘OFF’ potential measurements on pipeline system	Once every year
T/R system checks single source systems	One per month
T/R system checks multiple source systems	Once every 3 months
Data Logging at high risk locations to confirm current densities are within prescribed limits	Every 6 months
Remote monitoring	Monthly checks
Calibration of remote monitoring systems	1 to 3 years
Electrical inspection checks as required by BS 7671	Annual or as determined by the Operator RCD checks every 3 months

Table 5 Recommended test and inspection frequency for pipelines with an d.c. monitoring and mitigation system installed

Thus, as part of any maintenance survey the use of data loggers to record long term current density data would be of use to assist in an assessment of the d.c. corrosion risk.

The d.c. current density through coupons installed on a pipeline system should also be recorded and the direction of d.c. current flow.

It is important that all measurement equipment on pipelines affected by d.c. interference has the ability to record true d.c. potential data and has sufficient levels of a.c. rejection on the d.c. measurement circuit to ensure accurate d.c. pipe to soil potentials are recorded.

The d.c. current flow through each uni-directional bond should be recorded at regular intervals of at least once every month to ensure that the bond is still effective. If there is no d.c. current flow then there may be a problem with the blocking diodes, which would need further investigation.

The d.c. current variation over at least a 15-minute period should be monitored to ensure that there are no changes in current direction.

Where there are unidirectional or forced drainage, bonds installed the diodes should be check on a monthly basis as described in Appendix F. If there are two diodes installed in bond facility the frequency of checking may be extended.

12.2 Remote Monitoring

On pipelines affected by d.c. interference it is recommended that a suitable remote monitoring system is installed to record a.c. and d.c. pipe to soil potentials, d.c. current density and provide an alarm indication. The remote monitors should be installed at one or more high risk d.c. interference locations along a pipeline route on a pipeline that is affected by d.c. stray current interference.

Remote monitoring devices should be calibrated at regular intervals not exceeding 3 years to ensure that the data obtained is accurate. The calibration can be carried out at CP test facilities using calibrated test equipment rather than require the removal of the remote monitoring device and its return to the manufacturer. Remote monitor alarm settings should be set at appropriate values in terms of all parameters that are to be monitored, in particular d.c. current density magnitude and direction.

Some remote monitoring devices used to provide functional operation data will typically only take only one reading per day and transmit the data one per week. These devices are not data loggers they should only be used to provide functional operational data and provide an indication of an alarm situation.

The reading is often taken over a 1 second interval by the remote monitors that are generally employed in the UK. If the remote monitoring interval is set at once per day, then the time the measurements are taken should be one that reflects the maximum anticipated level of d.c. interference. This would be at 16.00 to 18.00 hours and not 01.00 hours in the morning when the current on a d.c. traction system would be expected to be low. It is important to confirm that any remote monitor records data at an appropriate time.

At all critical uni-directional bonds remote monitoring systems should be installed. If there is a change in the direction of the bond current flow, then this should create an alarm condition on the remote monitoring device. If the ON pipe to soil potential becomes more negative than -850mV vs $Cu/CuSO_4$ for prolonged periods of time, then that should also create an alarm condition

It may be necessary to change the alarm set potential to a value that does not result in frequent remote monitor alarms. This is because on pipelines affected by d.c. stray current interference there may be periods of time when the required-ON potential of -1,250mV vs $Cu/CuSO_4$ is not achieved and even setting a ON value as low as -850mV vs $Cu/CuSO_4$ may still create spurious alarms.

Where remote monitors are installed the data should be reviewed on a regular basis by operators.

There should be no requirement to visit bonds on a monthly basis where a remote monitoring device is installed. However, there is a requirement to inspect bonds that have remote monitors installed on at least an annual basis and those bonds without remote monitors installed should be inspected on at least a monthly basis.

If the remote monitor system produces an alarm e.g. low potential or reverse current flow, then this should be immediately investigated as a high priority, as it could mean that reverse current flow could be occurring.

12.3 Nature of Tests on Pipelines affected by D.C Interference

The following tests should be performed at CP monitoring locations on pipelines affected by d.c. interference:

- a.c. pipe to soil potential
- d.c. pipe to soil potential
- a.c. current density
- d.c. current density at a.c/d.c. coupon
- Coupon instant 'OFF' potential
- d.c. current flow through any bonds
- Corrosion rate from any ER probes that are employed

All measurements should be performed with calibrated test equipment and with multimeters capable of measuring true r.m.s. values for a.c readings. Current density readings through all coupons and probes should be recorded. The d.c. pipe to soil readings the mean, minimum and maximum values should be recorded using multimeters with the capability to take hi/lo readings.

Data logging of high risk d.c. current density locations should be conducted on a periodic basis to confirm the minimum, mean and maximum ON pipe to soil potentials, OFF coupon to soil potentials and current densities at selected test facilities.

12.4 Uni Directional Bonds

Uni-directional bonds should be checked on at least a monthly basis. Visual checks should be undertaken to confirm the condition of the bond.

The condition of the internal components should be checked to confirm their operating levels and that there is no overheating. The circuit protection fuse should be inspected and the current flow through the bond recorded.

It is essential to confirm the direction and magnitude of current flow and that the current flow is in the correct direction. The correct operation of the diodes should be confirmed using the guidance given in Appendix F of this GPG.

12.5 Over the Line Surveys

In the case of pipelines susceptible to d.c. stray current then conducting over the line surveys can be problematical.

To establish the interference free protection levels then CIP and DCVG surveys would need to be conducted at night when there are limited levels of d.c. stray current interference. However, such surveys will not reflect the levels of experience that will be experienced during normal operation. Additional guidance on over the line survey requirements is given in Sections 10.3 and 10.4

12.6 Data Interpretation

It is recommended that the data from any d.c. interference monitoring, and mitigation systems should be interpreted by a Level 4 BS EN ISO 15257 Certified Cathodic Protection Specialist or competent engineer approved by the pipeline owner/operator.

Such a review should be carried out at periodic intervals.

Pipeline Operators should note that even personnel certified to BS EN ISO 15257 Level 4 should have demonstrable levels of experience and competency in assessment of d.c. interference risks on pipelines affected by d.c. interference.

Monitoring stray current interference on pipelines systems can generate large volumes of data and often requires software that enables the data to be collated, analysed, and stored.

Data loggers should be able to provide information in an Excel format so that appropriate analysis of data can be conducted.

Data loggers are an essential requirement to ascertain the levels of both d.c. and a.c interference.

12.7 Design Documents

The design of any d.c. interference mitigation and monitoring system should comply with the relevant codes and standards identified in this GPG.

The operators Design and Management of Change procedures should be followed in relation to any d.c. interference mitigation system designs.

It is important that following on from any monitoring survey that a fully detailed report is issued. The report should contain the monitoring data as required in this GPG, the remote monitoring system data and any data logging information.

12.8 Corrosion Rate Measurements

Guidance on different methods that may be used to assess the corrosion rates on pipelines affected by d.c. stray current interference is given in Appendix G of this GPG

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[55] DIN 50929-3 Corrosion of metals - Corrosion likelihood of metallic materials when subject to corrosion from the outside - Part 3: Buried and underwater pipelines and structural components, DIN, 2018.

[56] BS EN ISO 8407:2014 Corrosion of metals and alloys. Removal of corrosion products from corrosion test specimens, BSI, 2014.

Appendix A: Abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
3LPE	Three Layer Polyethylene	kA	Kilo Amps
A	Amps	kV	Kilo Volts
AC	Alternating Current	m	Metre
ACVG	Alternating Current Voltage Gradient	MFL	Magnetic Flux Leakage
AGI	Above Ground Installation	MPAUT	Manual Phased Array Ultrasonic Thickness
BES	Battery Energy Storage	MPPT	Maximum Power Point Tracking
BS	British Standard	NACE	National Association of Corrosion Engineers
CIP	Close Interval Potential	ORR	Office of Rail Regulator now Office of Road and Rail
CP	Cathodic Protection	PCM	Pipeline Current Mapper
CRA	Corrosion Resistant Alloy	PD	Published Document
DC	Direct Current	PIG	Pipeline Internal Gauge
DCVG	Direct Voltage Current Gradient	PIV	Peak Inverse Voltage
DEP	Design Engineering Practice	PLC	Programmable Logic Controller
DLR	Docklands Light Railway	POD	Probability of Detection
DNV-GL	Det Norske Veritas Germanishe Lloyd	POI	Probability of Identification
EI	Energy Institute	PREN	Pitting Resistance Equivalent Number
EN	European Norm	PSR	Pipelines Safety Regulations
EPR	Earth Potential Rise	PV	Photo Voltaic
ER	Electrical Resistance	RBI	Risk Based inspection
FBE	Fusion Bonded Epoxy	RCD	Residual Current Device
FDIS	Final Draft International Standard	rms	Root Mean Square
GFPD	Ground Fault Protection Device.	RSSB	Rail Safety and Standards Board
GPG	Good Practice Guide	SAC	Signal Attenuation Current
GPR	Ground Potential Rise	SCADA	System Control and Data Acquisition
HDD	Horizontal Directional Drill	SCCS	Stray Current Collector System
HDPE	High Density Polyethylene	SCWP	Stray Current Working Party
HISC	Hydrogen Induced Stress Cracking	SSSI	Site of Special Scientific Interest
HSE	Health and Safety Executive	T/R	Transformer Rectifier
HVAC	High Voltage Alternating Current	TBN	Technical Bulletin Note
HVDC	High Voltage Direct Current	TP	Test Point
I/F	Isolation Flange	TPS	Traction Power Source

Abbreviation	Meaning	Abbreviation	Meaning
I/J	Insulation Joint	TS	Technical Standard
IEC	International Electrotechnical Commission	TS(Sen)	Train Stop Sensor
IET	Institute of Engineering Technology	TS(Sub)	Track Side Substation
IGEM	Institute of Gas Engineers and Managers	UPS	Uninterruptible Power Supplies
ILI	Inline Inspection	UT	Ultrasonic Thickness
ILIV	Inline Inspection Vehicle	V	Volts
ISO	International Standards Organisation	VLD	Voltage Limiting Device

Appendix B: Useful Information Definitions

The definitions applying to this GPG are given below:

A.C. corrosion: corrosion caused by alternating current, which originates from an external current source.

A.C. discharge device: a device blocking d.c. current but allowing the flow of a.c. current; used in the connection between a cathodically protected pipeline and an earthing electrode.

a.c Coupon: A circular 1 cm^2 surface area representative metal sample used to quantify the extent of corrosion, current discharge off the pipeline both a.c. and d.c. or the effectiveness of applied cathodic protection.

Alternating current voltage gradient (ACVG): An above ground surveying system that is used for the location and sizing of coating defects on buried pipelines. During ACVG surveys an alternating current is injected onto a pipeline. The current loss at coating defects is used to provide a qualitative assessment of defect size

Anode: Electrically – the positive electrode of an electrochemical cell, which emits current in the form of ionic discharge and corrodes and produces electrons. In the cathodic protection context, a device used to transmit protective current through an electrolyte to the metal to be protected (the cathode).

Bond: A piece of metal, usually in the form of rectangular strip, circular solid wire or stranded conductor, usually of copper, connecting two points on the same or on different structures to prevent any appreciable change in the potential of one point in respect of the other.

Capacitive coupling - the transfer of alternating electrical signals or energy from one segment of a circuit to the other using a capacitor.

Cathode: Electrically – the negative electrode of a cell. In the cathodic protection context, it is the term given to the structure to be protected and where the cathodic reaction occurs, which in soil is reduction of dissolved oxygen in water.

Cathodic Disbondment - Cathodic disbondment is the loss of adhesion between a coating and its metal substrate due to the products of cathodic reduction reaction (corrosion reaction) that take place in the interface of coatings. Cathodic protection (CP) systems are installed to prevent corrosion of the metallic substrate. Disbondment of coating occurs when coatings in a cathodic protection system interact either chemically or physically, ultimately causing corrosion beneath the coating that may be detached by the application of excessive levels of CP.

Coating: Electrically insulating covering bonded to a metal surface for protection against corrosion by preventing

Conductive coupling: Occurs when a part of the current belonging to the interfering system returns to the system earth via the interfered system

Continuity bond: A bond designed and installed specifically to ensure the electrical continuity of a structure. This may be permanent or temporary, in the latter case it is used to connect two sections of a structure, which would otherwise be disconnected during the course of modification or repair.

Copper/copper sulphate reference electrode: A reference electrode consisting of copper in a saturated copper sulphate solution.

Coupon: A representative metal sample of known bare surface area used to quantify the extent of corrosion or the effectiveness of applied cathodic protection or a.c. interference.

Corrosion rate: the rate of corrosion (metal dissolution). Corrosion rate is expressed as weight loss per unit of metal area and unit of time (g/m^2 and year) or as loss of metal thickness per unit of time (µm/year = 0,001 mm/year). Weight loss can be recalculated into loss of metal thickness. The rate of localised corrosion is usually expressed as depth penetration per unit of time (µm/year).

Current density (on metal surface): current per unit metal surface area, usually expressed as Am^{-2}

DC decoupling device: A protective device that will conduct D.C. current when pre-determined threshold DC voltage levels are exceeded but will allow A.C. current to flow at all A.C. voltages.

Depolarisation: The change in the potential of the cathode as a result of cessation of current flow and is a time dependent process.

Direct current voltage gradient (DCVG): An above ground surveying system that is used for the location and sizing of coating defects on buried pipelines. During DCVG surveys, the cathodic protection current is pulsed. A sensitive milli-voltmeter and two copper-copper sulphate reference electrodes, placed about one metre apart by the surveyor, are typically used for surveying purposes. Thus, the potential gradient associated with coating defects can be identified and assessed to provide a qualitative assessment of defect size.

Direct drainage bond: Device that provides electrical drainage by means of a direct bond between an affected structure and the stray current source.

Drainage (electrical drainage): Transfer of stray current from an affected structure to the current source by means of a deliberate bond

Drain point: The location of the negative cable connection to the protected structure through which the protective current returns to its source.

Earthing resistance: the electrical resistance between a metal surface (e.g. the steel surface in a coating holiday on a buried pipe, or an earthing electrode or an a.c. power line pole foundation) a remote earth.

Earth Potential Rise (EPR): the increased potential of an a.c. tower earthing point and the surrounding soil due to earth currents, especially the high fault current at a phase-to-earth fault in an a.c. power line tower. The potential rise may also be caused by a lightning strike to the tower, and which may result in a phase-to-earth fault. The EPR is a function of the a.c. tower earthing and the soil resistivity.

Electrical resistance probe: Probe where metal loss is measured by comparison of the calibrated resistance value of a piece of metal with known physical characteristics

Forced drainage bond: Device that provides electrical drainage by means of a bond between an affected structure and the stray current source.

Free corrosion potential (natural potential): The potential of a corroding surface in an electrolyte relative to a reference electrode.

Groundbed: A system of buried or submerged electrodes connected to the positive terminal of an independent source of direct current, in order to lead to earth, the current used for the cathodic protection of a buried or immersed metallic structure.

Ground potential rise (GPR): The maximum electrical potential that a substation grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum grid current times the grid resistance.

NOTE—Under normal conditions, the grounded electrical equipment operates at near zero ground potential. That is, the potential of a grounded neutral conductor is nearly identical to the potential of remote earth. During a ground fault the portion of fault current that is conducted by a substation grounding grid into the earth causes the rise of the grid potential with respect to remote earth.

Holiday: A hole, break or other discontinuity in the coating on a pipeline, which causes the pipe surface to be exposed.

IR error: This is the error contained within the pipeline potential recorded at ground level remote from the actual pipe surface. This error is caused by the flow of cathodic protection currents and the resistance of the soil and coating.

Impressed current: The current supplied by a rectifier or other direct-current source, (specifically excluding a galvanic anode), to a protected structure in order to attain the necessary cathodic protection.

Inductive coupling the coupling between two electric circuits through inductances linked by a common changing magnetic field.

Insulated flange: A flanged joint between adjacent lengths of pipe in which the nuts and bolts are electrically insulated from one or both of the flanges by the use of insulating sleeves and the jointing gasket is non-conducting, so that there is an electrical discontinuity in the pipeline at that point.

Insulated joint: A manufactured joint or coupling between two lengths of pipe, inserted in order to provide electrical discontinuity between them.

Instant 'OFF' potential: The structure to electrolyte potential that is obtained immediately after the disconnection of the structure under CP from the CP current source. This is sometimes referred to as the polarised potential and is the true pipe to soil potential excluding any voltage created by current flowing through the soil and pipeline coating.

Interaction test: A test to determine the severity of corrosion interaction between two buried or immersed structures.

Interference phenomenon resulting from conductive, capacitive, inductive coupling between systems, and which can cause malfunction, dangerous voltages, damage, etc.

interference voltage - voltage caused on the interfered system by the conductive, inductive and capacitive coupling with the nearby interfering system between a given point and the earth or across an insulating joint.

Natural potential: See free corrosion potential.

Peak Inverse Voltage: The maximum value of reverse voltage which occurs at the peak of the input cycle when the diode is reverse-biased.

Permanent reference electrode: A permanently buried or immersed reference electrode designed for long life and installed close to the structure to enable the structure potential to be measured.

PREN: The PREN, is the Pitting Resistance Equivalent Number. The higher the PREN the better the corrosion resistance. The elements that have the most beneficial effect in terms of corrosion resistance are, chromium, molybdenum and nitrogen. The relative concentration of these materials is used to determine the PREN by the following equation.

PREN= % Cr + 3.3%Mo + 16% N

Polarisation: An effect of electrolysis, which occurs, on either the anode or the cathode of a cell when gas or chemical products form on the electrode. The polarisation effect is to increase the circuit resistance of the cell thus reducing the current for a given voltage.

Polarised potential: The potential between a reference electrode and the pipeline, which exists immediately after an interruption of the CP current, (i.e. instant off potential).

Reference electrode: A device used to compare potentials at various locations by providing a standard for potential measurement. Electrodes may be made of zinc, copper in a saturated copper sulphate solution or silver and silver chloride in a chloride ion solution of known concentration.

Remote earth: Theoretical concept that refers to a ground electrode of zero impedance placed an infinite distance from the ground under test

Sacrificial anode: An anode that relies on a natural potential difference as a source of power. The ‘driving voltage’ can be found from the electrochemical series. Metals generally used as galvanic

Sampling rate: Measurement interval set by the operator

Stray current: Incidental current picked up by a structure from adjoining foreign sources.

Soil resistivity: specific resistance of a soil to carry electric current. Soil resistivity is expressed in Ω m (earlier in Ω cm). The lower the soil resistivity, the easier it is for electric current to flow through the soil. Fine-grained soils with water holding capacity (clay, silt, peat etc.) usually have low resistivity, whilst coarse grained and water draining soils (sand, gravel, till etc.) usually have a high resistivity. The water and salt content of the soil have a large influence on the resistivity. A high water and a high salt content results in a lower resistivity. Road de-icing salt, which is drained through the soil, lowers the soil resistivity.

Spread resistance: ohmic resistance through a coating defect to earth or from the exposed metallic surface of a coupon to earth.

Note 1 to entry: This is the resistance which controls the d.c. or a.c. current through a coating defect or an exposed metallic surface of a coupon for a given d.c. or a.c. voltage.

Sulphate-reducing bacteria (SRB): These act as depolarisation agents in the soil around the structure and are harmful to the cathodic protection effect. They achieve this by reducing sulphate ions to sulphide and consuming the hydrogen of the polarisation film. They occur in anaerobic soil conditions and can result in relatively high rates of corrosion.

Telluric effect: A natural phenomena caused by solar activity deforming the earth’s magnetic field causing low frequency current to flow in the general mass of earth. Telluric currents can result in stray current interference on long pipelines.

Touch voltage: The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure.

Unidirectional drainage bond: Device that provides electrical drainage by means of a unidirectional bond between the affected structure and stray current source

Voltage Limiting Device: Protective device whose function is to prevent existence of an impermissible high touch voltage

Appendix C: D.C. Rail Traction Interference

C1 General

This Appendix of the GPG provides information on the subject of stray current interference from d.c. operated rail traction systems. The information has been included as an Appendix to the GPG as not all UKOPA members have pipelines that are affected by stray current interference from d.c. traction systems. This Appendix is therefore only relevant to operators where there are d.c. traction systems present. It has been provided to give guidance for pipeline operators affected by stray current from d.c. traction systems and to provide a source of general information for pipeline operators that do not have pipelines affected by d.c. traction interference.

The effects and management of d.c. interference from rail traction systems is provided by the ORR in its Tramway Technical Guidance Note 3 -Design Standards Stray Current Management.

The supply voltages for d.c. traction systems are detailed in BS EN 50163 [48] and IEC 60850-:2014 [49]

Energy Safe Victoria [50] also provides guidance on the management of d.c. traction interference.

Section C2 of this Appendix provides general information on the operation of the different d.c. traction systems that are encountered in the UK.

C2 DC Traction Systems

C2.1 London Underground

The London Underground traction system is termed a fourth rail d.c. power system. There are two running rails used for the railway carriages, which do not carry current and two used for the d.c. traction power circuits, which do carry current.

The fourth rail carries the electrical return current that on third rail and overhead d.c. transit networks is carried by the running rails.

On the London Underground a top-contact third rail is laid beside the track, energized at +420 V d.c. and the top-contact fourth rail is located centrally between the running rails at −210 V d.c. The two conductors combine to provide a traction voltage of approximately 630 to 650 V d.c.

The London Underground electrical system was introduced because of the problems of return currents, originally intended to be carried by the earthed running rails, flowing through the iron tunnel linings on the older underground lines. If the running rails carrying current were earthed this could cause stray current corrosion and even arcing, if the tunnel segments were not electrically bonded together. The problem was enhanced because the return current could also flow through nearby iron pipes forming the buried water and gas mains and this resulted in stray current corrosion on buried utilities.

The four-rail system assists in reducing the risk of stray current corrosion by reducing the extent of current flow through earth. Although the d.c. supply has one side linked to earth for safety reasons, the connection is through resistors, which ensure that stray earth currents are kept to manageable levels.

There is generally not a significant problem with stray current interference on buried pipelines from the London Underground system but there is still some limited stray current from the underground that can flow through the general mass of earth and affect buried utilities..

Thus, whilst the London Underground circuits discharge d.c. current to earth the extent of stray current interference is generally limited and within manageable limits. Nevertheless, suitable test facilities should be installed on any new pipeline systems installed close to the London Underground our other fourth rail systems to ensure that the levels of d.c. interference can be monitored.

CP test facilities should include a pipe test connection, a coupon with an exposed surface area of $1cm^2$ and a permanent reference electrode.

CP monitoring facilities should be readily accessible by the pipeline operator.

C2.2 D.C Light Railway Circuits

The Docklands Light Railway (DLR) and other Light Railway systems use a third rail system.

A third rail is a method of providing electrical power to a railway system, through a continuous rigid conductor placed alongside or between the rails of a railway track or in the case of urban metro systems the power conductor is routed overhead. The running rails carry the d.c. traction return current that with the London Underground is carried by the fourth rail.

In the case of the DLR the positive live rail is located on the outer edge of the track on insulated supports (see Figure C1). Most metro systems will operate at 750V d.c. the actual operating voltage and current of any new light railway or Metro system should be established with the system operator.

Figure C1. DLR System where outer rail on insulated supports is the +750V rail

The running rails take the return current, but they do have some degree of insulation from the general mass of earth. This is to limit current flow through earth and the rate of corrosion of the rail lines where any current leaves the traction system.

BS EN 50122-2 [51] states that "Experience *has proved that there is no damage in the tracks over a period of 25 years, if the average stray leakage current per unit length does not exceed the following value:*

I'max = 2,5 mA/m

(average stray current per length of a single-track line).

NOTE 1*: For a double track line the value for the maximum average stray current should be multiplied by two. For more than two tracks the value increases accordingly. For the averaging process, only the total positive parts of the stray current over 24-hour multiples are considered*."

There is however some d.c. current flow in the general mass of earth from Light Railway and Metro systems as the return rails are not completely insulated from earth. Some light railways have a separate earth matt located at the d.c. substations to collect current flow in earth along with connections to the return rails. The earth matts act as a preferred path for current flow rather than other buried metallic structures and the earth system is termed a SCCS or stray current collector system.

Thus, whilst the London Underground circuits discharge a limited d.c. current to the general mass of earth the extent of current from Light Railway and Metro systems is often greater but is still a lot lower than in the case of the third rail system on the UK's Southern and South Western Region railway lines.

The permissible leakage current for a d.c. operated traction systems are detailed in BS EN 50122-2 [51]. IEC 62128-2 [52] provides the international guidance with regards to provision against the effects of stray currents caused by d.c. traction systems, which may differ slightly from the guidance given in BS EN 50122-2 [51].

C2.3 D.C. Traction Systems

In the case of the mass transit d.c. operated traction systems the running rails are not effectively insulated from earth and significant levels of d.c. current do flow in the general mass of earth from the rail system. It is understood that the older rail lines in the South of England operate at 660V and the newer lines operate at 750V.d.c.

It is where the current flow from the d.c. traction system leaks to earth and is picked up by buried pipelines that corrosion can occur. The corrosion may occur where the current discharges off a pipeline to return to the d.c. power source, which would typically be at a pipeline railway crossing.

A schematic representation of a third rail d.c. traction system is shown on Figure C2, whilst Figure C3 shows the d.c. power system configuration on a third rail train system in operation.

Where the d.c. traction current that leaks off a d.c. traction system return conductors, flows through the general mass of earth and enters a pipeline, it will cause the pipeline to be cathodically protected or achieve partial levels of CP. The current entering the pipeline system will lower the pipe to soil potential at the current entry location and would not be detrimental.

Pipelines will act as a low resistance path through the soil for traction system current to return to the d.c. traction system power source. However, where a pipeline crosses a railway line or runs in close proximity to it the current may leave the pipeline at coating defects. At the point or points where the current discharges off a pipeline then the pipeline may suffer accelerated corrosion. There will be anodic current discharge and the pipe to soil potential will move in a positive direction i.e. become less electronegative.

The pipe to soil potential at the pipeline crossing point with the railway would generally vary quite considerably as a result of d.c. interference. The d.c. current that would flow in the return rails can leave the rails and be picked up by buried pipelines in the vicinity of the rail line. It will return to the d.c. power source at the pipeline rail line crossing point or where the rail line and pipeline are in close proximity to each other see Figure C4.

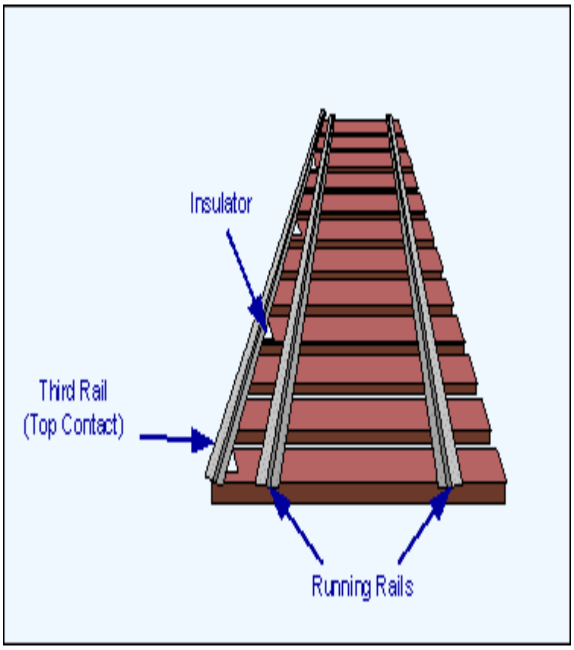

Figure C2. D.C. Third rail system schematic

Figure C3. Southern Region Third rail system running rails are joined via impedance bond and outer rail carriers the D.C Live conductor

Where current leaves the traction rails it can result in metal loss on the traction circuit. It is for the latter reason that rail operators try and limit the magnitude of any d.c. leakage current to prevent damage to the running rails.

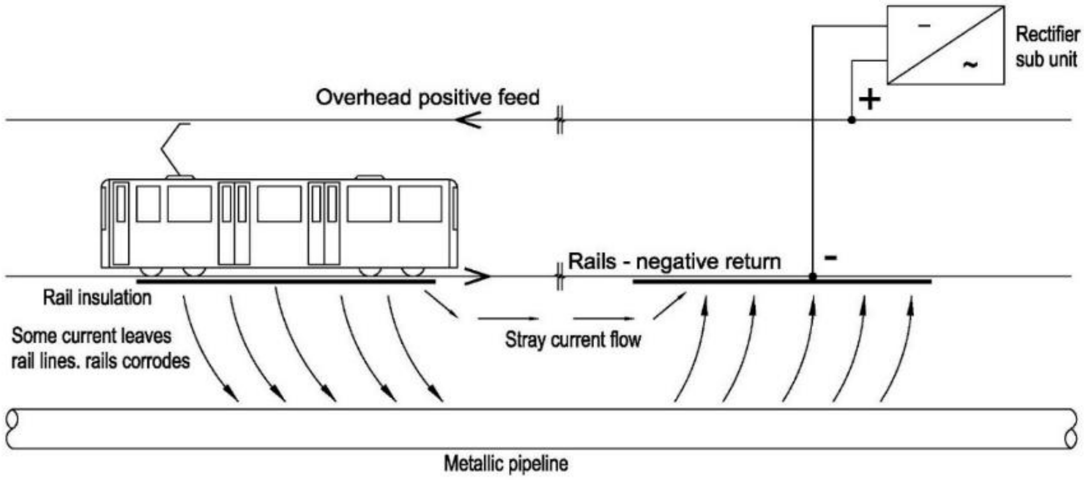

Figure C4. D.C. Third rail system stray current effects

If there is no stray current interference, then the pipe to soil potential would remain constant. Thus, at night-time when there is no current flowing in the d.c. traction system the pipe to soil potential will remain relatively stable. However, during the day current from d.c. traction systems may leave the traction circuits and enter a pipeline system and the pipe to soil potential will fluctuate see Figure C5.

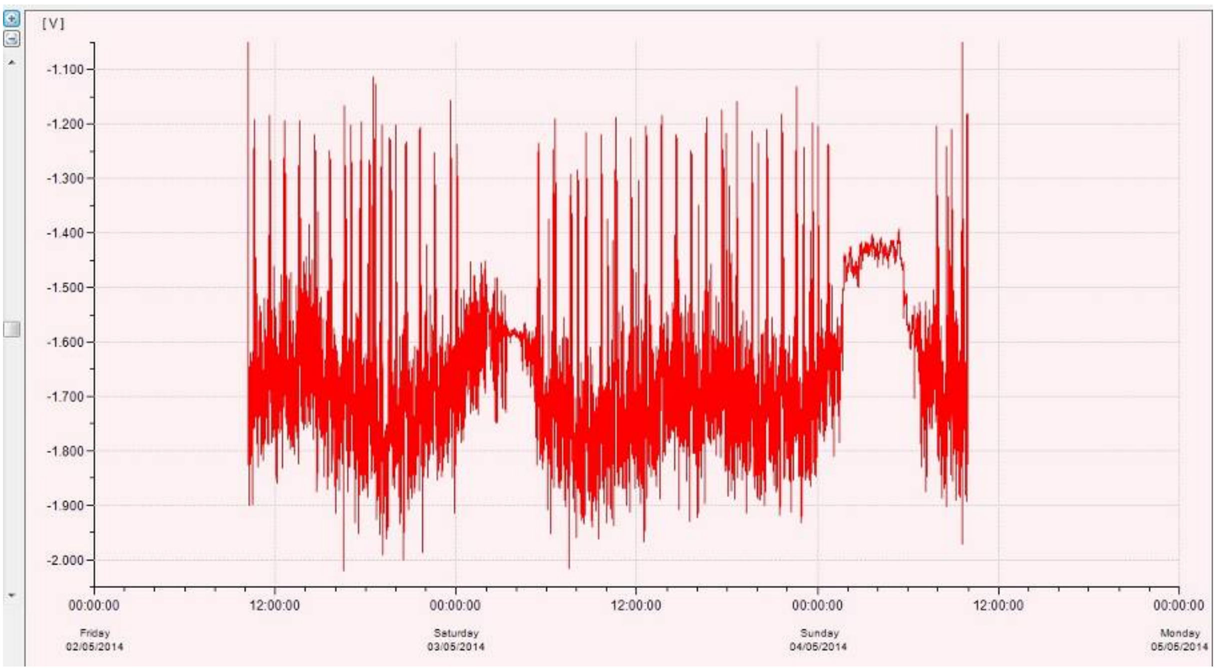

Figure C5 Typical pipe to soil potential variation over time on a pipeline at a rail crossing

The extent of interference depends on the current flow through the generally mass of earth, insulation resistance of the return rails from earth, rail system operating current, substation location, number of trains on the rail system, magnitude of current picked up by the pipeline, pipeline coating type, current load that each train is drawing, whether a train is accelerating or braking, whether regenerative breaking employed and relative position of the trains on the rail line in relation to the pipeline.

D.C. traction system current flow is not an easy system to model and the primary method to gain data on interference levels is to record pile to soil potential readings over time to see if there is a time dependent variation in the pipe to soil potential.

BS EN ISO 21857 [1] does give guidance on how d.c. stray current interference can be modelled and should be referred to for guidance. There are methods of modelling d.c. stray current and commercial software is available to carry out such studies, if required.

If there is a variation in the pipe to soil potential on the pipeline when the d.c. traction system or systems are in operation this would be indicative of stray current interference. In the case of d.c. traction systems during periods of time when no trains are running then stable or relatively stable pipe to soil potentials will be recorded. The pipe to soil potential during the period of time that there is no d.c. interference is termed E_{ref} or the reference potential (see Section 5.8 of this GPG)

The pipe to soil potential variations will also be lower over a weekend when the train frequency is reduced.

The rail bond has ensured that there are no positive excursions in pipe to soil potential but due to the magnitude of d.c. current flow there are significant negative excursions in pipe to soil potential experienced.

It can be seen that the pipe to soil potentials are stable during the night when there is no current flow in the d.c. traction system as trains are not running but the d.c. traction system is still energised,

C3.0 Design and Operation of d.c. traction systems

C3.1 General

Where new d.c. transit systems are to be developed there should be liaison between the Developer, other utilities and the pipeline operator.

D.C. traction systems can cause stray currents, which could adversely affect both the railway concerned and/or outside installations, when the return circuit is not sufficiently insulated from earth. The major effects of stray currents can be corrosion and subsequent damage to metallic structures, where stray currents leave the metallic structures. There is also the risk of overheating, arcing and fire and subsequent danger to persons and equipment both inside and outside the railway or trolley bus system.

The following systems, which can produce stray currents, shall be considered:

- D.C. railways using running rails carrying the traction return current including track sections of other traction systems bonded to the tracks of d.c. railways.
- D.C. trolleybus systems which share the same power supply with a system using the running rails carrying the traction return current.
- D.C. railways not using running rails carrying the traction return current, where d.c. currents can flow to earth or earthing installations

The Developer of the new works should contact affected pipeline operators at as early a stage as possible in relation to any new schemes and preferably during the planning application stage.

Such liaison should continue throughout the construction and initial operational phase until any adverse effects have been identified and resolved and there is a high level of confidence that corrosion damage is unlikely. Thereafter, liaison should continue at a lower intensity throughout the life of the pipeline and transit system.

The Developer should note that that consideration should be given to the possibility that cathodic protection systems may also interfere with transit system infrastructure such as signalling equipment.

Joint interaction testing should be undertaking to determine if any adverse effects exist and the possible effect CP systems may have on the d.c. traction system should be addressed during the traction system design phase.

The guidance in the ORR Tramway Technical Guidance Note 3 [18], BS EN ISO 21857 [1] and any standards the pipeline operator may adopt to manage d.c. stray current interference risks on its pipeline systems should be followed. It should be noted that gas pipeline operators in particular in the UK often have their own specific requirements

The need for diversions of existing pipelines should form part of the planning process. Cast and ductile iron mains transporting natural gas operating at <7bar, which cross any proposed track bed should normally be replaced with HDPE pipe for a minimum distance of 10 metres on either side of the proposed track.

In the case of petroleum product or high-pressure gas pipelines, it would not be possible to use HDPE either because of the pipeline diameter, pressure or product being transported, in which case isolation joints should be installed each side of the rail crossing.

I/Js installed each side of a rail crossing should be considered to mitigate the stray current interference risk and also to separate the pipeline system into sections where the d.c. interference risk can be managed.

The earthing system on d.c. railways is designed to limit stray d.c. currents so that the surrounding infrastructure does not suffer stray current corrosion. However, there will always be some stray current in the system, as no rail system can have an infinite resistance to earth.

It is essential that suitable test facilities are installed each side of isolation joints. Provision should be made in the CP test facility for I/Js to be able to be bonded in the future if required. Bond cables where installed shall have a minimum cross-sectional area of 35mm^2. Current carrying cables shall not be used for potential measurement purposes and wherever bond cables are installed a separate potential measurement cable should also be installed

Technical Guidance Note 3 [18] issued by the Office of the Rail Regulator -Design Standards Stray Current Management provides guidance on stray current interference mitigation measures.

C3.2 Stray Current Monitoring Forum

As part of the design and planning process for any new rail traction system technical contact details should be agreed between all parties and a forum should be organized at regular intervals during the design and planning process between the Developer, the rail operator and pipeline operator or operators.

However, once a project has been completed technical forums should still be organized between the pipeline operator and the rail system operator where matters relating to the stray current interference monitoring and testing could be discussed and any appropriate actions taken.

The rail system operator should be obliged to notify the pipeline operator if there are any changes to the rail system that could affect the levels of stray current interference and provide relevant technical information on request. The requirements for any forum should be included in contractual documentation between the pipeline operator and rail system operator.

C3.3 Stray Current Mitigation Measures Rail Bodies

A technical note should be produced by the designers of any new d.c. traction system that will be routed close to or parallel existing pipelines. The technical note should detail how any d.c. stray current interference risk will be controlled.

A stray current collection system (SCCS) is a means to pick up the stray current that leaks from the running rails and can provide a low resistance path for the stray current itself, thus avoiding possible interference with third-party infrastructures. The SCCS is connected to the TPS via a blocking diode to facilitate the collection of d.c. current. There are four measures available to minimize stray current emission from a d.c. traction electrification system:

- Insulation of the traction return circuit with respect to earth.
- improvement of the conductivity of the traction return circuits back to the substation.
- Improvement of conductivity of designated stray current return circuit and design of the SCCS.
- Configuration of the traction power supply system.

The following measures should be incorporated into the design and construction of any traction system to mitigate stray current interference and its effects:

- The rails, cables and conductors forming the return circuit should be deliberately isolated from earth. The rail return system should be insulated from the general mass of earth at all points including at the negative busbar within any new TSS. Rail to earth resistance will be designed to be a minimum 5 Ω.km on the line.
- All rail fixings and supports should include an insulator in their assembly to limit the amount of current that can pass.
- No connections should be permitted between the rails and the general mass of earth except that necessary for safe operation i.e. a voltage limiting device.
- To maintain continuity all rails should be bonded with continuity bonds longitudinally at adjustment switches or any other discontinuity and cross-bonds should be made as required.
- Periodic cross bonding of rail-to-rail at maximum 200m intervals and track-to-track at maximum 400m intervals should be installed on all trackforms in order to parallel the rails and reduce the resistance of the traction return current path.

A SCCS may be installed based on dedicated under track reinforcing bars that are structurally isolated from the rail structural reinforcement and bonded to a continuous Stray Current Collection Cable (SCCC) at periodic intervals. The system if installed should be run continuously for the full length of the line without breaks and terminated at test points at each TSS.

- Following handover of the system into service, rail potentials at substations, and where installed, collector system current and voltage should be monitored via any SCADA system.

- Rail potential measurement locations at midpoints between TSSs should be provided and terminate within appropriate enclosures so that if required the maximum rail line potential can be recorded.

- Adequate drainage should be provided on all trackforms to ensure no water pools around the rail shoes and compromise the stray current mitigation measures.

BS EN 50122-2 [30] advises that "The most important influencing variable for stray currents leaving the tracks is the conductance per unit length between track and earth. The corrosion rate on the rail line due to d.c. current leakage is the main aspect for the assessment of risk.

C3.4 Voltage Limiting Devices

VLDs permit fault currents to discharge from a pipe to the rail traction earth, if the voltage exceeds a pre-determined value. The use of VLDs is identified in BS EN 50122-2 [51] and they are used to prevent hazards voltages being present.

They are primarily used to mitigate touch potential risks.

They can be provided for both a.c. and d.c. circuits and act in a similar way to surge protection devices. Where the devices are used, they must have the necessary Rail Authority Certification and require inspection at pre-determined intervals. If used for pipelines affected by d.c. traction interference the risk of pipeline damage by the d.c. fault currents must be considered.

The Office of Rail Regulator advises that "All voltage limiting devices used shall meet the requirements of Clause 7.4 of EN 50122-2 [51] in terms of reset after operation. Ideally this should have the facility to be monitored through the SCADA system.

Experience has shown that there is a particular failure mode with some types of voltage limiting devices. If they experience a high fault current or a large number of operational duty cycles due to short-term impermissible accessible voltages, then they may fail in the short circuit mode. This then creates a direct path to earth for the traction return which could if undetected for some time lead to corrosion on other nearby metallic structures. Testing and maintenance procedures must take account of this failure mode.

For this reason, hybrid switching types composing of a solid-state control and separate d.c. contactor is preferred"

Thus, if a VLD device is considered then the risks of direct connection to a pipeline must be fully evaluated and a remote monitoring device shall be connected to the pipeline system to warn of an alarm situation. If a VLD is installed, then the pipeline operator must ensure any alarm systems are effectively monitored and managed to warn of a direct connection between rail system and buried metallic utilities.

In the case of d.c. traction systems connection of the pipeline direct to the rail return can have serious consequences in terms of damage to a pipeline. Thus, wherever possible the use of VLDs on d.c. traction systems should be avoided.

If the use of a VLD cannot be avoided, it will be essential that in the event of a fault or VLD failure that prompt immediate action is taken to rectify the fault.

C.4.0 D.C Transit System Planning and Construction

Tram or d.c. traction system designs may have a major impact on the likelihood of significant stray current interference.

Although stray current cannot be completely "designed out", the Developer of a transit system should be encouraged to consider these issues and adopt best practice throughout the planning and construction phase. The primary means of minimising earth leakage is maximising rail to earth resistance, which can have an impact on the levels of interference.

If routing of the railway is such that long parallelisms with pipeline systems, and/or close proximity between transit system sub-stations and pipelines cannot be avoided, the requirement for uni-directional drainage bond(s) for the safe return of stray current to the sub-station should be considered and included in the system design if required.

Note: Drainage bonds between pipelines and rail lines may increase the magnitude and extent of the stray current and may also increase the corrosion rate of the running rails and therefore require the specific approval of the railway authority. Wherever possible drainage bonds should be avoided.

Experience has shown that where rail bonds can be avoided then they should. Detrimental levels of interference are not always obtained after removal or disconnection of rail bonds and in some cases disconnection of rail bonds can reduce the level of pipe to soil potential excursions at bond locations.

Extensions to existing d.c. systems may change the stray current pattern and consideration should be given to repeat monitoring for a minimum of 24 hours at test points, which are available at different locations. Monitoring in terms of data logging should ideally be conducted during weekdays when there is a greater number of trains running. The data logger monitoring frequency should be at periods no greater than once every 5 seconds and ideally at 1 to 0.5 second intervals.

C4.1 Requirements for CP Test Facilities

CP test points should be located where the greatest pick up and leakage of stray current is anticipated. These locations include close to sub-stations, SCCS sites, transit vehicle stops, inclines, rail and pipeline crossings, at intermediate locations along a pipeline route or at locations where there is known to be a low resistivity environment.

During the design of any CP system as a result of d.c. traction interference modifications to the existing CP test facilities may need to be undertaken to ensure that they have coupons and reference electrodes installed, whilst new CP system facilities may need to be installed.

CP test facilities on pipelines affected by stray d.c. current should have at least one 1cm^2 exposed surface area coupon and permanent reference electrode. It may be beneficial to include additional coupons that can be exposed at a later date and also provide ER probes at critical locations.

The d.c. discharge current densities at test facilities with coupons installed should be monitored to determine the direction and magnitude of d.c. current flow onto or off a pipeline system.

A switching device included in the data logger measurement circuit should also be included so that coupon instant OFF measurements can be taken a regular interval. Installation of electrical resistance (ER) probes should be considered at important locations such as proximity to d.c. system sub-stations or at pipeline/railway crossing points. ER probes can give a direct read out of corrosion rate.

Experience has shown that where ER probes that require manual measurement of probe resistance at periodic intervals are used they are not in practice monitored at the required frequency and consideration should be given to the use of ER probes that can be monitored remotely.

There should also be buried permanent copper/copper sulphate reference electrodes at test facilities to enable measurement of pipe to soil potentials close to the pipeline.

Coupons are a section of steel of known surface area that have a cable attached and are connected to the pipeline via a CP post. The cable should preferably be attached to the cable in the factory under controlled conditions. If the cable is disconnected and an ammeter/shunt is inserted into the cable between the coupon and pipeline then it is possible to measure the current flowing onto the coupon to effect cathodic protection and the current flowing off the coupon, if the coupon is suffering detrimental stray current interference then current will flow off the coupon. It is important to note that the d.c. discharge current density does vary over time, as it is dependent upon the current load on a railway system.

The preferred method of current measurement is by means of either a zero-resistance ammeter of a 1 or 10-ohm shunt so that the maximum voltage drop across the shunt does not exceed 10mV when current flows. Typically, either a 200mA /200mV (1 Ohm) or 20mA/200mV (10 Ohm) shunts would be used.

In areas of concern in relation to d.c. stray current it would be necessary to install data loggers to monitor the time dependent variation of d.c. current density and d.c. pipe to soil potential over time to fully assess the risk of d.c. corrosion. The data loggers should be able to record minimum, maximum and mean values with a sampling rate of at least one reading every second but ideally up to once every 1 to 0.5 seconds.

On new pipeline systems the date of coupon installation should be recorded so that if a coupon is excavated at some stage in the future for laboratory examination then with a knowledge of the date of installation it is possible to calculate the average corrosion rate following on from any laboratory examination. Where the test cables need to be placed in a surface box in the roadway, the box should be of adequate size to house a data logger. The construction of the test facility shall be sufficient to ensure no water ingress into any test equipment. The requirement for any new CP test facilities shall be identified during the pipe or traction system design phase.

C4.2 Pre-Construction CP “Fingerprint” Monitoring

At least one year before construction of a new traction system, monitoring on protected steel pipelines in the vicinity of the proposed track and at any location that is believed may be influenced by stray current interference from transit system operations should be undertaken to provide a “fingerprint” of the status of the CP system.

Fingerprint testing should be carried out at all test locations deemed to be influenced by transit system operations. At each test location measurement of pipe to soil potential, polarised coupon potential shall be recorded for a minimum of 24 hours and preferably over a 48-hour period. The testing shall be repeated during each season of the year. Where coupons are installed data loggers to record d.c. current density variation and d.c. ON and OFF pipe/coupon to soil potential variations. In the case of d.c. traction interference data logging should be performed at between 0.1 to 5 second intervals.

“Fingerprint” data should be compared against data recorded following operation of the transit system to allow a clear association of the any stray current to the source.

Although other Utilities may develop their own monitoring strategy and test sites, a co-operative approach with close liaison and exchange of information would benefit all parties.

Note: *Entire pipeline systems cannot be monitored, and it is often not possible to collect data continuously at all test points. Although test points should provide representative data for the system, it is possible that some interference will not be detected. For this reason, it is desirable that all Utilities share their stray current data, e.g. a utility showing unusually high levels of interference in a particular* *area could indicate a change in the stray current in that area, which could affect all Utilities. Unusual excessive interference in a particular area could be due to a maintenance problem on the railway*

C5.0 Over the Line Surveys

Prior to energisation of any new d.c. traction system and before normal train operations commence it is recommended that CIP and coating defect surveys such as DCVG, ACVG or SAC are conducted on all pipeline sections likely to be affected by the stray current interference.

If any significant coating defects are identified they may need to be repaired or their locations at least accurately identified.

Once stray current interference occurs it is often difficult to conduct CIP surveys and effectively analyse data because of the fluctuating d.c. pipe to soil potential. Conducting a CIP survey prior to the energisation of the traction system would provide good base line data on the CP status of a pipeline.

It is important that all coupon locations are benchmarked when a DCVG survey is conducted and all DCVG indications are recorded in terms of % IR no matter how small. Small coating defects are those where if detrimental levels of stray current interference were to be present then corrosion would most likely occur.

Where GPS coordinates are used for coating defect locations, they should be able to provide a high level of location accuracy less 1m and ideally prior to conducting excavation works a repeat coating defect survey should be conducted to accurately pinpoint coating defect locations to minimise excavation costs.

C6.0 Energisation of D.C. Traction Systems

Following energisation of the d.c. system and before normal train operations commence, monitoring at all applicable test points should be carried out to establish the influence of powering up (energising) the d.c. system.

C7.0 Operation of DC Traction Systems

When a d.c. transit system commences normal operations, CP monitoring should be carried out at all test points installed for monitoring tram or traction system operations. The monitoring should be carried out every three months for a period of two years or until sufficient confidence, (whichever is the minimum), is established in the data.

BS EN 50122-2 [51] specifies the requirements for protective provisions against the effects of stray currents, which result from the operation of d.c. traction systems. The standard applies to all metallic fixed installations which form part of the traction system, and also to any other metallic components located in any position in the earth, which can carry stray currents resulting from the operation of the railway system.

BS EN 50122-2 [51] applies to all new d.c. lines and to all major revisions to existing d.c. lines. Whilst BS EN 50122-3 [53] applies to Electrical safety, earthing and the return circuit mutual interaction of a.c. and d.c. traction systems.

It should be noted that the latter standards are only applicable in Europe with IEC 62128-2 and IEC 62128-3 [54] being equivalent but with minor differences and adopted throughout the rest of the World.

Routine monitoring checks should include data logging over a representative period of time e.g. > 24 hours.

Monitoring of d.c. transit systems is in addition to and should not replace the requirement for normal routine CP monitoring carried out in accordance with the and Management Procedures for cathodic protection of buried steel systems.

Other sources of information, which can inform and support the monitoring strategy may be obtained from routine in-line inspection data or checks for corrosion made during any other opportunities to inspect the pipeline during excavations for other works.

The stray current performance of a d.c. transit system is dependent upon effective monitoring and maintenance by the system operators, e.g. early detection of damaged rail insulation, poor cross bonding, high ballast and water ponding etc. is essential to maintain the stray current performance of the system. It is the responsibility of the rail operator to carry out these tasks.

It should not be assumed that satisfactory stray current performance established by post commissioning monitoring will be maintained throughout the life of the system. Therefore, on-going monitoring of stray current interference and regular liaison with the rail system operator by the pipeline operator and the other utilities is essential.

There should be a means of information exchange between pipeline and d.c. traction system operators so that relevant monitoring and d.c. traction system operating data can be shared e.g. current levels on traction system and current flowing through any SCCS.

C8.0 Operation of D.C. Traction Systems

C8.1 General

Bonds are sometimes installed to combat or manage stray current interference from d.c. traction systems. The bond is generally made between the pipeline and the d.c. traction system negative or return conductor.

Where such bonds are made, they will not be as a direct bond as directly bonding a pipeline to a rail line can result in accelerated corrosion on the pipeline.

Bonds where employed on d.c. traction systems should be designed to carry current in only one direction namely from the pipeline to rail line and not vice versa.

Return rails on d.c. traction systems can have voltages in the region of 60V or greater and could create significant damage to a pipeline if directly connected.

In the UK pipeline industry rail bonds were often installed as a matter of good practice in the past and sometimes without a sound technical justification for the requirement to install a bond. It is important that operators of pipeline to railway traction system bonds inspect the bonds at regular intervals typically on a monthly basis but also carry out tests to determine whether a bond is actually required in a given situation to mitigate the d.c. stray current interference risk.

It is essential to confirm that bonds are unidirectional, and any diodes installed have not failed.

There are different types of rail bond. There can be unidirectional bonds or forced drainage bonds and are described in the following sections. Consideration should also be given to the installation of remote monitoring devices at critical bond locations to warn of an alarm situation.

C8.2 Inter- Pipeline Bonds

Inter pipeline bonds are installed on pipeline systems to ensure that where pipelines are routed in parallel, they are bonded to the common CP system. All inter pipeline bonds on a pipeline system should be located and identified. If a bond fails, then it could mean that one pipeline is electrically isolated from the other pipelines and may be susceptible to stray current interference. The responsibility for the maintenance of inter-pipeline bonds should be agreed between the respective pipeline operators.

Where there are bonds between different pipeline systems to mitigate stray current interference effects then there should not be a reliance on a single bond as in the event of failure any stray current interference effect can be exacerbated. Thus, at least two inter-pipeline bonds should be installed.

It is particularly important that at drain points where there are bonds to multiple pipelines that effectives of the inter pipeline bond is confirmed by measurement of the current flow to each pipeline and its potential. If a pipe connection fails, then there may be an enhanced stray current interference risk and possibility of failure of a pipeline.

The current flowing in all inter pipeline bond cables should be checked as if there is no current flowing it could indicate failure of bond and that a pipeline may not be receiving effective levels of CP or could suffer localised stray current interference.

Such a situation would require investigation.

C8.3 Unidirectional Bonds

In the case of a unidirectional drainage bond the drainage current can flow only in one direction. Therefore, the unidirectional drainage bonds may be used, where the potential of the interfered structure is not always more positive than the potential of the d.c. source, e.g. d.c. traction systems. In the case of direct drainage bonds, it is often necessary to include a resistor into the bond to limit the current flow. It is essential that suitable circuit protection in the form of a fuse or MCB is installed to limit the current flow in the circuit especially in the event of diode failure, which may connect the pipeline directly to the d.c. traction circuit.

Wherever practical two diodes should be installed in series in any unidirectional bond to provide redundancy in the event of a diode failing short circuit.

The bond is not intended to be the only means to provide cathodic protection to the structure that is subject to interference.

The extent of interference on a pipeline depends on the current flow through the general mass of earth, insulation resistance of the return rails from earth, rail system operating current, substation location, number of trains on rail line magnitude of current picked up by the pipeline, pipeline coating type, current load that each train is drawing, whether a train is accelerating or braking and relative position of the trains on the rail line in relation to the pipeline.

Where regenerative braking systems are employed on traction systems these can draw extra current from the TPS and also influence the extent of stray current interference.

D.C. traction system current flow is not an easy system to model and the primary method to gain data on interference levels is to record pile to soil potential readings over time to see if there is a time dependent variation in the pipe to soil potential.

If there is a variation in the pipe to soil potential on the pipeline when the d.c. traction system or systems are in operation this would be indicative of stray current interference. In the case of d.c. traction systems during periods of time when no trains are running then stable or relatively stable pipe to soil potentials will be recorded. The pipe to soil potential during the period of time that there is no d.c. interference is termed E_{ref} or the reference potential

Rail bonds should ensure that there are no positive excursions in pipe to soil potential but due to the magnitude of d.c. current flow there are significant negative excursions in pipe to soil potential experienced.

It can be seen where rail bonds are installed that the pipe to soil potentials are stable during the night when there is no current flow in the d.c. traction system as trains are not running,

Figure C6 show the typical pipe to soil potential variation on a pipeline at a crossing of a d.c. rail crossing line but with no bond installed at the rail crossing. The train frequency is low at one train every 15 minutes.

The rail bond has ensured that there are no positive excursions in pipe to soil potential but due to the magnitude of d.c. current flow there are significant negative excursions in pipe to soil potential experienced.

It can be seen that the pipe to soil potentials are stable during the night when there is no current flow in the d.c. traction system as trains are not running,

The extent of interference depends on the current flow through the generally mass of earth and the rail bond.

It should be noted that at some rail bonds recent experience has shown that if the bond between the pipeline and rail line is disconnected then the levels of stray current interference can actually be reduced.

In relation to pipeline crossings of sources of d.c. stray current interference e.g. d.c. traction system return, conductors a minimum separation of 3.0m is typically required between pipelines and rail lines based upon design code requirements

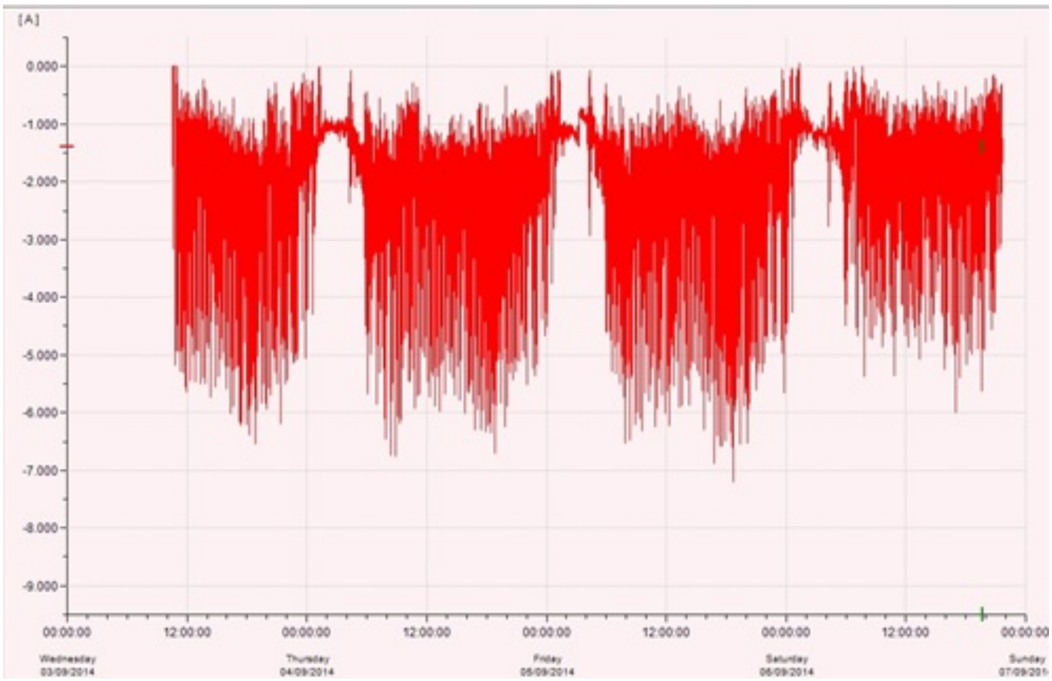

Figure C6. Typical Pipe to Soil Potential Variation at Rail Bond

. The construction arrangement for a typical unidirectional bond is shown on Figure 7C

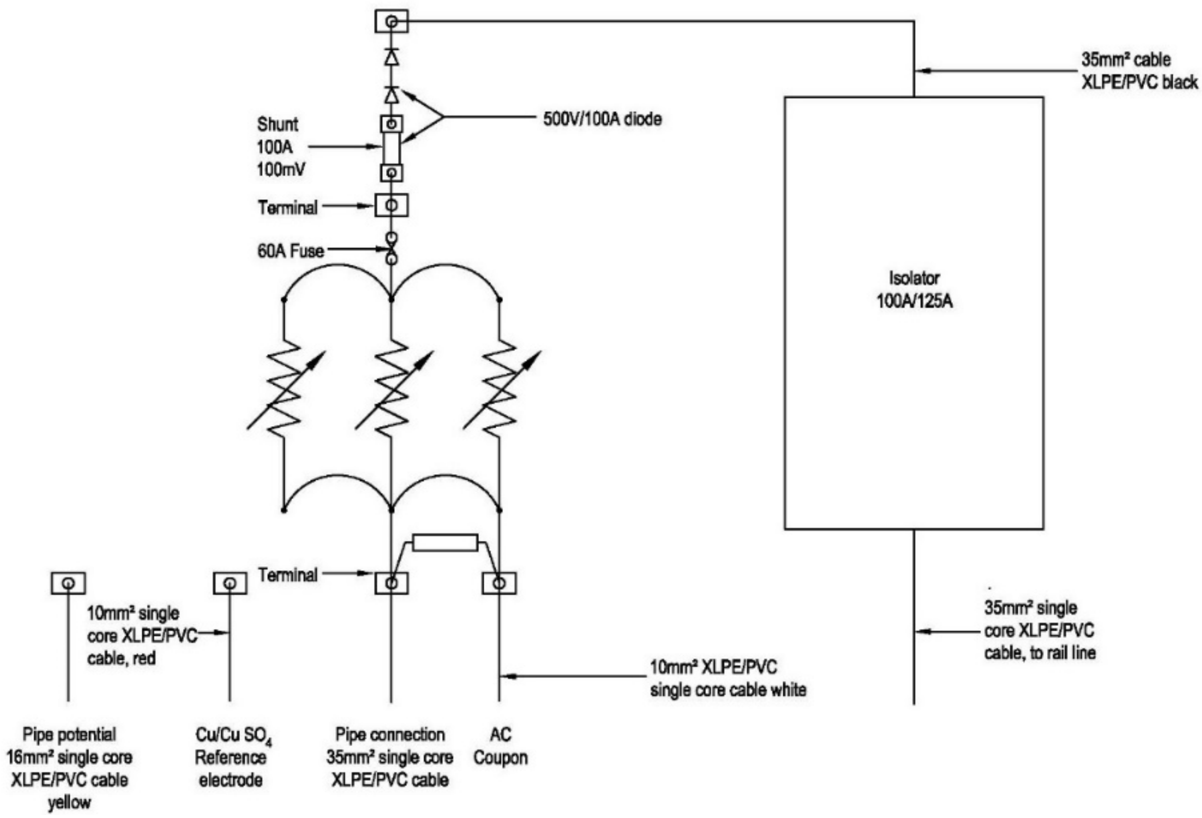

Figure C7. Typical Unidirectional Bond Arrangement.

A unidirectional bond does not require an a.c. supply to operate**.** Unidirectional bonds would typically be installed at rail crossings to drain stray current picked up on a pipeline back to the traction circuits. Unidirectional bonds should ideally contain two diodes in the traction circuit connection so that in the event of closed-circuit failure of one diode the other diode would still operate and prevent the traction circuit being directly connected to the rail line.

There should be two pipe connections one for current and the other for potential measurement. Suitably rated resistors with current measurement facilities and circuit protection and also limit the return current magnitude.

An isolator should also be installed so that the traction connection can be isolated to permit safe working on the bond and a suitably protected connection to the traction circuit so that the traction circuit voltage can be recorded if required.

Permanent reference electrodes and coupons should be installed, and consideration should be given to installation of remote monitoring devices. Protective covers should be provided at rail traction return connections as the rail traction rail voltage can under certain circumstances exceed 60V.

C8.4 Forced Drainage Bonds

Generally, a forced drainage bond is used when a direct or unidirectional drainage bond does not drain all stray current from the interfered structure, because the interfering structure does not have a sufficiently negative potential. The technique is used where the stray current originates from a d.c. traction system.

A forced drainage bond incorporates a transformer rectifier or thyristor-controlled device in the bond between the interfered structure and the source of interference. Forced drainage bonds require an a.c. supply typically 230V and the bonds should be included in the pipeline operator's electrical equipment register and checked at periodic intervals as required by BS 7671 [28] to confirm their electrical safety.

They also require a connection to the d.c. traction system as the d.c. traction return rails are used often used as a groundbed. Forced drainage bonds consist of a thyristor/diode bridge that will allow current to flow through the bond to maintain a set pipe to soil potential. The bond will contain resistors to limit the current flowing in the circuit and the thyristors will conduct current to ensure that the required pipe to soil potentials are achieved. Once the required pipe to soil potential is achieved then the bond will cease to conduct.

There is generally a PLC included in the circuit so that the required operational parameters can be set e.g. required limiting structure to electrolyte potential and also to display operating voltages and currents.

Suitable monitoring facilities will be included to ensure current; rail traction system voltage and potential are recorded together with suitable circuit protection. An isolator should be included in the circuit to ensure that the traction connection can be isolated for bond maintenance.

Where a transformer rectifier is installed to act as the forced drainage device then preference should be given to the use of an independent groundbed and not to use the rail traction circuits as the groundbed.

C8.5 Specific Requirements Rail Bonds

Monthly checks are recommended on all bonds. If monthly checks are not conducted it is recommended that a remote monitoring system is installed at the bond locations to identify alarm situations and record data that would be recorded as part of routine functional checks.

The remote monitor system should record the bond current and direction. If the direction of the bond current changes i.e. it is not from pipeline to rail but from rail to pipeline, then that should trigger an alarm situation. Immediate action would be required, and the bond disconnected.

The remote monitoring device should also record pipe to soil potential a.c. /d.c. and coupon current flow. Alarm settings should be selected to ensure that critical situations are identified e.g. anodic current flow.

Periodic checks should be taken at all bonds. These will include bond condition, checking protective devices and condition of blocking diodes. If the pipeline was to be inadvertently connected to the d.c. power source accelerated corrosion of the pipeline can occur and failure can occur.

Appendix D: Internal Corrosion Risk on I/Js From D.C. Interference

Mitigation	Advantages	Disadvantages
Short Circuit I/J	This would mean no potential difference across an I/J and stray current interference should not occur as both sides of the I/J would be at the same potential	CP levels on pipelines may be compromised and the pipeline CP system may not be able to provide the required current to ensure effective levels of CP on a cross-country pipeline with the I/Js shorted.
Apply CP to Dead side of any I/J	The I/J would not need to be short circuited but application of CP to the pipework on the Dead side of an I/J could mean that the potential on the AGI or Dead side of an isolation joint could be made the same as the potential on the pipeline. The potential difference across the I/J could be reduced to a low value and the reduction in potential difference significantly reduce the internal stray current interference risk.	New CP systems would need to be installed on the station or Dead side of the I/Js. There may be other stray current effects to be considered on other structures and pipeline CP system may need to be modified. Such a modification could be expensive to implement as a considerable amount of additional current capacity would be required.
Switch OFF CP on pipeline	If the pipeline CP is switched OFF the source of the stray current would be removed, and natural potentials would exist each side of I/J	Such a situation may not comply with pipeline design code guidance or local statutory legislation. Possible risk of corrosion on pipeline if CP is off.
Install resistive bond across I/Js	Would reduce the potential difference across the I/J and rate of stray current corrosion.	Would not completely eliminate stray current interference as potential difference would still exist across I/J all be it at a lower value. If installed in hazardous area resistive boxes would need EExd certified enclosures and resistors can also fail in the event of voltage surge across I/J.
Remove conductive liquid from line	No conductive liquid no stray current corrosion	Disadvantage may not be a practical option for the process system.
Install a spool piece	BS EN ISO 15589-1 does recommend use of spool piece in such a situation to reduce but not eliminate stray current interference	This may not be practical due to the extremely low resistivity of produced water which may even preclude the use of a spool piece. It is often not practical to retrofit spool pieces.
Adjust CP system Operational Levels	Reduces risk of embrittlement and cracking on duplex lines, reduced power consumption from CP system and reduces potential difference across I/J and hence stray current risk	No real disadvantages here as protection levels should ensure that pipeline CP levels are still within criterion

Mitigation	Advantages	Disadvantages
Reduce temperature at I/J	This will increase resistivity of process product. Higher the temperature greater is pitting risk	Reduction in temperature of process system may not be possible

Table D1 Summary of Mitigation Measures Advantages and Disadvantages

Item	Recommendation	Benefit
1.0	Water Composition Review	Would assist in identifying level of corrosion risk and also in risk ranking of I/Js where corrosion failure could occur in the future
2.0	Review CP data	The CP data should be reviewed it may be possible to look at reducing the potential difference across the I/Js by reducing the ON potential for the protected side of a pipeline
3.0	I/J specification	Operators should review their I/J specifications as the coating system employed in I/Js must be suitable. A detailed specification for I/Js should be considered and if defects in coating system on Dead side of I/J current could be localized at isolated coating defects resulting in high pitting rates
5.0	Apply CP the station side of the I/J	If CP was applied to the station side of the I/Js this may be difficult and could require significant levels of extra current capability. Each case would need to be assessed on merits
6.0	Specification review	Pipeline operators would need to assess what changes are required to the design specifications to ensure effective levels of CP are obtained on pipelines and are not exposed to a HIC risk on susceptible materials
7.0	Change joint orientation	If I/J is installed vertically then water may not be able to collect across joint during stagnant conditions
8.0	Internal anodes	In some cases, on non piggable lines sacrificial anodes have been installed on the DEAD side of the I/J these corrode in preference to the parent metal. Not always practical
9.0	IJ storage	Need to ensure I/Js stored so that coating not exposed to UV radiation as direct UV radiation can increase internal fluid temperature

Table D2 Summary of Recommendations

Appendix E Stray Current Interaction Testing

E.1 General

This Appendix specifically relates to stray current interference interaction testing on a pipeline operator's pipelines from third party pipeline systems and vice versa. However, it can and should be applied where applicable to stray current interaction from other sources of d.c. current than pipeline CP systems.

This Appendix has been based upon the original guidance given in the now withdrawn standard BS 7361 Part 1. The guidance in BS 7361 Part 1 [28] was particularly useful and provided good, detailed information on how to manage the d.c. stray current risk from pipeline CP systems, which is not provided in the more recent EN standards.

To ensure that Cathodic Protection schemes for one pipeline do not affect other buried utilities and other CP systems do not cause any detrimental stray current interference on new or existing pipelines it is essential that testing of the system is undertaken where necessary. Prior to final commissioning of a new CP system, a notice should be sent to all other utilities that have buried metallic plant in the vicinity of the CP system.

Suitable facilities should be made available to interrupt the flow of current from anode groups or groundbeds to facilitate interaction testing.

Modern coating systems employed on new pipelines mean that the CP system current requirement is low and as a result new pipeline system do not generally cause stray interference on third party pipeline systems that are crossed. Thus, interaction testing is often not carried out on new pipelines even though it is a pipeline design code requirement. However, older pipelines have coating systems that require a relatively high current density to ensure effective levels of CP and their CP systems operate at relatively high current outputs e.g. > 5A. Thus, CP system on older pipeline systems can cause stray current interaction on new pipeline systems where there are crossings or parallel route sections.

Guidance on stray current interference is given in BS EN ISO 21857 [1] but the guidance does not really address interaction testing requirements from different pipeline CP systems. If a third party organisation installs a d.c. current source within the vicinity of an pipeline e.g. a HVDC transmission system, solar farm, d.c. transit or traction system or other d.c. current source then stray current interference can occur from such systems and measures should be taken to reduce the risk of interference on buried assets. The information in this Appendix primarily concentrates on interaction and testing on CP systems associated with pipelines.

E.2 Notification

E2.1 Notifying owners of other structures

Throughout the planning, installation, testing, commissioning and operation of a new cathodic protection scheme or d.c. current source, details of the d.c. system should be given to all organizations and owners having buried metallic pipes, cables or other structures in the near vicinity of the installation.

When conducting a search to determine the proximity of existing services to a new pipeline then a distance of 500m from the new pipeline should ideally be considered. However, the minimum proximity distance considered should not be less than within 200m of a new pipeline.

These notices are intended to ensure that information becomes available to enable a CP system or d.c. powered system to be installed in such a manner that corrosion interaction is kept to a minimum and that enough information is given to other organizations to enable them to determine whether corrosion interaction is likely from any new system.

The notification of stray current interaction testing need only be sent to organisations who have indicated, in reply to a preliminary notification in Section E2.2, that they have structures likely to be affected by the operation of the new scheme.

E2.2 Preliminary notification

At an early stage during the planning of a new pipeline system and its associated cathodic protection scheme, a preliminary notification should be sent to each organization having buried metallic structures near the proposed installation. The notice should include, as far as possible, the following information, (including any relevant drawings):

whether sacrificial anodes or an impressed current system will be employed,

a) information as to the route or site of the structure to be cathodically protected,

b) position of groundbeds or anodes if known at this stage,

c) approximate dates by which the system is likely to be ready for commissioning.

> *NOTE The preliminary notice should not be delayed unduly if all the information is not readily available*.

The notice should also include a request for any particulars required relating to the buried structures belonging to the other organizations in the area, for use in designing the CP scheme to give the minimum levels of corrosion interaction.

It is particularly important to identify the location of third-party pipeline groundbeds along a pipeline route. Since if a groundbed is located too close to a pipeline e.g. within 400m it may cause stray current interference on the new pipeline.

In some instances, it may be necessary to re-route the pipeline or relocate the third party groundbed to mitigate interference on the new pipeline system.

E2.3 Further Notification

if any of the information listed in Section E2.2 is not available at the time of preliminary notification, this should be supplied to the third-party pipeline operator or structure owner at least one month before the date proposed for corrosion interaction testing. In particular, the sites of proposed impressed current groundbeds should be notified an appreciable period of time before pipeline construction commences.

In the case of sacrificial anode installations, the information provided should show the relative positions of the anodes and the primary and secondary structures. It may often be possible for the parties to agree that interaction testing is unnecessary in the case of sacrificial anode installations

E2.4 Notification of Corrosion Interaction Testing

After commissioning tests have been completed on the pipeline CP system notification should be sent to all organizations who have indicated that they have structures likely to be affected by the operation of the scheme. The following information should be supplied at least one month before the date proposed for interaction tests:

the anticipated current at which each rectifier or sacrificial anode will be operated during interaction tests.

a) an indication of structure/soil potentials along the primary structure before and after the application of protection.

b) dates for the tests.

At the time of the tests, there should be available to all participants, suitably scaled plans/drawings showing the layout of the primary and secondary structures at the test locations together with the locations of the cathodic protection installations, drawn up from information supplied by both the operator and the other interested parties. The information should include details of the nearest T/R units to the test location and the operating currents to the third-party structure owner CP system.

The third-party structure owner and the new pipeline system operator should also provide details to each other of the T/R units on the respective pipelines.

E2.5 Interim and Subsequent Notification

If, after preliminary notification, or at any time after the cathodic protection scheme has been brought into regular service, it is found necessary to alter the scheme substantially, details of the proposed amendments should be sent to all organizations having buried metallic structures near the cathodic protection scheme.

E3 Design Requirements

Once details of third-party pipeline systems and d.c. power sources have been established during the notification period then the CP system design for the new pipeline system can be determined.

It is important that any design of any new pipeline CP system follows the guidance given in this GPG and in relation to stray current interference the guidance given in BS EN ISO 21857 [1] as applicable.

Third party pipeline operators should be contacted to ascertain their requirements with regards to interaction testing and any requirements that they may have for any additional test facilities or CP system monitoring equipment at any pipeline crossing point. This should include new CP test facilities, coupons, reference electrodes and any sacrificial anodes installed to mitigate possible stray current interference risk.

The design of the CP system for any pipeline should ensure that there are test facilities installed as close as reasonably practical to the third-party pipeline crossing.

E4 Interaction Testing

E4.1 Stage at which interaction tests should be conducted

At least one month should be allowed, if required, for the owners of nearby structures to examine details of the proposed scheme and to respond so that the operator may arrange for interaction tests.

Tests should be made within three months of switching on the new cathodic protection and after the CP system has polarised.

E4.2 Tests to assess corrosion interaction

The changes in structure/electrolyte potential due to interaction will vary along the length of the secondary structure and a negative potential change at any point will often indicate the presence of positive changes at other parts of the structure.

For most metals, only positive potential changes above the free corrosion potential are liable to accelerate corrosion. The object of interaction testing is, therefore, to find the areas where the potential change is positive, to locate, by testing a number of positions, points at which the potential change locally reaches a maximum and to assess each maximum value with sufficient accuracy.

In the case of discontinuous structures (such as mechanically jointed pipelines) it is essential that each discontinuous section should be treated as a separate structure for testing.

In certain cases, negative changes of potential in excess of the level that would be needed for cathodic protection may adversely affect the structure or its coating.

The current used for the test should be the maximum required during normal operating conditions to give the level of cathodic protection required on the protected structure.

The criterion to be monitored is the magnitude of the change of potential of the primary and secondary structures with respect to the environment that occurs when the impressed current cathodic protection system is switched on and off or when the sacrificial anodes are connected/disconnected.

NOTE When, as is normally the case, the positive terminal of the meter is connected to the pipeline , the potentials measured are usually negative and a change in the positive direction will be indicated by a reduction in the reading displayed on the meter.

The change recorded should be that change clearly seen to be due to the switching on of the cathodic protection unit, not more than 15s being allowed for the instrument to indicate the resulting change of structure/electrolyte potential before the reading is taken. If there are also fluctuations of potential due to the effects of stray currents from other sources, then only those changes caused by the switching on of the cathodic protection system should be recorded.

During interaction testing a suitable timing device (typically set 16 at seconds on, 4 seconds off or similar cycles where the ON period is longer than the OFF period) should be used at each protective current source.

Four periods of time ON and one period of time OFF are typically used for CIP and interaction testing to avoid structure depolarisation and ensure a clear distinct between when a potential change occurs so that it can clearly be seen whether the potential change occurred during a period of time when the CP power source was ON or OFF.

For multiple sources of protective current, the timers must be synchronised to switch on and off together. Adequate readings should be taken to identify the region of maximum potential change.

Several observations should be made at each location and compared. In marginal cases, the number of observations should be increased and examined for consistency. This is of particular importance at positions where tests indicate that the changes in the positive direction on the secondary structure are locally at a maximum.

The position of the reference electrode is important, and it should be placed directly over the structure under test.

It is important to synchronize the measurement of structure/electrolyte potential with the switching of the CP system power sources.

The change in structure/electrolyte potential resulting from the cathodic protection should be measured at a sufficient number of points, generally working outward from the CP system groundbed, and with the spacing being sufficiently close, to give an overall picture of the distribution of structure/electrolyte potential change.

Detailed attention should be given to crossing points or points of close proximity between the primary and secondary structures and to regions where the change produced has been found to be in the positive direction.

Where more than one cathodic protection transformer rectifier unit is installed on a particular structure, the combined effect should be ascertained. Arrangements should be made for all units which cause an appreciable effect at the position of tests, to be switched on and off or connected and disconnected simultaneously.

All site testing should be witnessed by representatives of both the foreign structure owner and the new pipeline system operator

A stray current interference test record sheet on which to record the data obtained during the interaction testing should be agreed by the respective pipeline operators. The information should include the following data:

Date of Test:

Pipeline systems under test

Switching Period: Seconds ON and Seconds OFF

TABLE E1 TR Unit Data

Transformer Rectifier Operational Settings					
TR Location and Designation	**Pipeline Operator**	**DC Voltage (Volts)**	**DC Current (Amps)**	**Drain Point Potential V vs $Cu/CuSO_4$ ON**	**Drain Point Potential V vs $Cu/CuSO_4$ OFF**

Table E 2 Test Location Details

Pipeline Under Test	Location	Pipeline Under Test Potential Volts vs $Cu/CuSO_4$ Third Party CP System ON	Pipeline Under Test Potential Volts vs $Cu/CuSO_4$ Third Party CP System OFF	ΔV mV

Pipeline Project Representative:

Signature

Date:

Third Party Pipeline Representative:

Signature:

Date:

On completion of testing, the results must be sent to each of the pipeline owners.

E4.3 Information required during and at the completion of interaction tests

The protection current measured at each transformer rectifier during interaction tests, and the finally agreed currents to be employed as a result of any remedial measures, should be notified to all organizations attending the tests and all authorities who have indicated that they have structures likely to be affected by the operation of the scheme.

E4.4 Tests after remedial measures have been applied

Further testing may be required after agreed remedial measures have been applied.

If, after providing bonds between two structures or fitting sacrificial anodes in order to reduce

interaction, the structure/electrolyte potential of the secondary structure is found to be appreciably more negative than that measured with the cathodic protection switched off during the initial interaction testing, this will normally be sufficient indication that the mitigation procedure is achieving its purpose.

The criterion should be the change of the structure/electrolyte potential between the original condition with the cathodic protection switched off and the final remedied condition with the cathodic protection operating, switching and bonding or anode connection being carried out quickly to minimize any effects of variations from other sources. Guidance on the most appropriate action to mitigate any interference situation should be sought from a specialist CP Engineer.

E4.5 Repeat tests

When the cathodic protection system is put into service, arrangements should be made for repeat tests to be made on neighbouring structures at 2-year intervals or at intervals agreed between the parties concerned depending on the magnitude of the structure/electrolyte potential changes observed. The necessity for re-testing should also be considered when changes are to be made to either the primary or the secondary structures or their cathodic protection systems. If there is an increase in the current output from any of the CP T/R units then repeat interaction testing should be conducted.

E.6 Sacrificial Anode Systems

Suitable facilities should be made available to interrupt the flow of current form anode groups to facilitate interaction testing.

Where the total current output from an anode or group of anodes is less than 100mA, interaction testing may not be required. However, stray current interference testing notifications should still be sent to third party structure owners as detailed above. The responsibility for testing or not still remains with the other utilities even if the current exceeds 100 mA, corrosion interaction is unlikely, particularly if anodes are placed at least 2 m away from any secondary buried structure and so that the secondary structure does not lie between the anode and the primary structure. If anode current outputs in excess of 100 mA are used, or groups of anodes installed together are used, or if anodes are sited so that another underground metallic structure lies between the anode and the primary structure, interaction testing should be.

E.7 Interaction Testing Criteria

The criteria for assessing stary current interaction is detailed in Section 5 of this GPG and BS EN ISO 21857 [1].

E.8 Remedial measures to reduce interaction

Where interaction testing confirms changes in potential in excess of the limits detailed in BS EN ISO 21857 [1], the following remedial measures should be undertaken in order of preference:

a) Optimisation of current output (reduce level of current output to minimum level whilst still maintaining a satisfactory level of protection)

b) Installation of sacrificial anodes on the foreign structure.

c) Resistive bonding to the foreign structure.

d) Direct bonding to the foreign structure.

The use of (c) and (d) above should be avoided if possible, they both rely on current being drained to the foreign structure to restore its natural potential. Prior to any adjustment being made to the CP system, authorisation must be gained from the engineer responsible for the pipeline system re-testing the CP system may then be required.

E.8 Special considerations

A further interference situation can arise with railway track signalling systems. This is not strictly corrosion interaction, but the signalling can be adversely affected in some circumstances by the flow of d.c. current through the general mass of earth.

Liaison with the owner of the track network must be carried out to agree the test regime before the CP system is commissioned. It is essential that the rail track operator be provided details of the proposed CP system. In the case of the effect of solar farms, HVDC. transmission systems and d.c. traction systems on pipelines specialist advice may be required. Negative polarisation on pipelines constructed from CRAs can also result in a HISC risk and can be detrimental to such pipeline systems and specialist advice should be sought in such situations.

Appendix F Testing of Diodes and Thyristors

F.1 General

This Appendix provides information on how diodes in unidirectional bonds and thyristors in forced drainage bonds may be tested.

F.2 Operational test of thyristor & resistance test of diodes

F2.1 Thyristor testing

The typical connection arrangements are as shown in Figure F1 Gate and cathode leads must be disconnected before testing if the thyristor is in a circuit. The following checks will give a good indication of the thyristor. It will detect marginal or voltage sensitive units.

a) Connect the negative lead of an ohmmeter to the anode connection and the positive lead to cathode, the resistance should exceed 1 Megohm (see Figure F1)

b) Reverse the ohmmeter leads from step a. The resistance again should exceed 1 Megohm.

c) As shown in Fig FG2, connect X to Y and using a 6V battery the d.c. voltage should read 6 Volts. Touch wire Z momentarily to gate and the d.c. voltage reading should drop to less than 1 Volt. Open the X-Y connection and the d.c. voltage reading should return to 6 Volts.

NOTE: - Devices can be tested without removing from heatsink. All connections must be removed, and the thyristors checked one at a time. The heatsink being treated as the anode (A) connection.

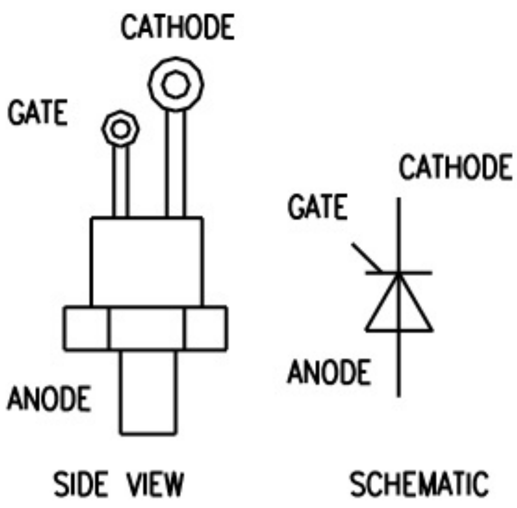

Figure F1 Thyristor connection Details

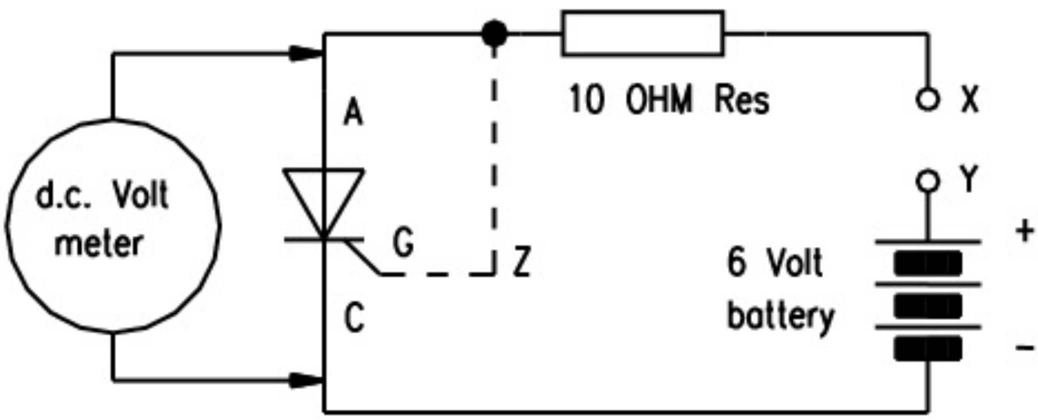

Figure F2 Thyristor Test Diagram

F2.2 Diode testing

To check diodes a multimeter on ohms range can be used as shown in Figure F3. If the results of the test comply with the connections procedure shown, then the diode should be suitable for service. If high or low resistance is shown for both connections, then the diode must be replaced. If there is a low resistance for both connections arrangements then the diode has failed close circuit and if the diode was installed in a unidirectional or forced drainage bond then the pipeline would have been directly connected to the traction circuits and further investigation would be required as the pipeline may have been exposed to an enhanced corrosion risk.

NOTE: - *For cathode stud devices the opposite arrangement to the connections shown is correct.*

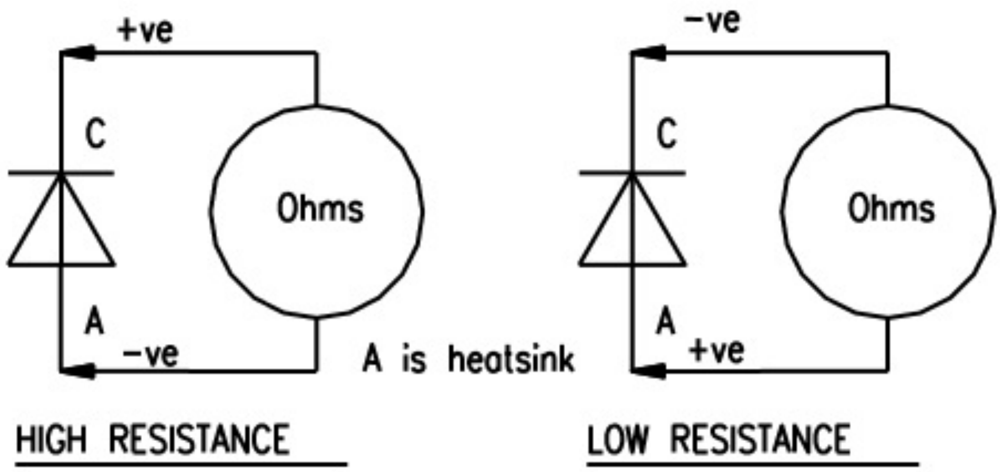

Figure F3 Diode test method

Appendix G Corrosion Rate Monitoring and Assessment

G1 General

This Appendix specifically address the options available to pipeline operators to ascertain the corrosion rate or likely corrosion rate on pipelines affected by d.c. stray current interference.

These options include the use of ER probes, laboratory examination of coupons installed on pipelines exposed to d.c. stray current interference, the use of inspection vehicles or excavations to a pipeline to examine over the line survey features.

Stray current interference monitoring data can also be used to provide an indication of likely corrosion rates on pipelines affected by d.c. stray current interference and the methodology for this approach is indicated in Section 5 of this GPG. However, the use of coupon current density data will only provide indicative qualitative informative data on likely corrosion rates and should not be considered to provide quantitative data.

G2 ER Probes

The ER probe technique can be applied for corrosion rate assessment as an alternative to the weight loss coupon. Unlike the weight loss coupon, the ER probe technique does not require excavation and weighing procedures, since any mass loss is assessed by an electronic means.

At critical locations where, high rates of stray current interference and corrosion may be experienced ER probes can be installed .ER probes can also be used to provide information on monitoring of other electrical characteristics e.g. a.c. and d.c. current density, pipe to soil potential and spread resistance. They can be capable of local manual or remote access measurement.

Operators would need to assess, based upon the nature of the risk, whether it is necessary to install such monitoring equipment on a pipeline. In the UK the use of ER probes with elements of exposed surface area 1 cm^2 has been used in the past specifically with reference to a.c. interference but they may also provide data on the levels of corrosion risk from d.c. stray current interference.

Ideally ER probes with a 1cm^2 exposed surface area should be considered, as this has been shown to be the coating defect surface area that exhibits the highest corrosion risk and would represent the exposed surface area of a typical coating defect or Holiday on a modern coating system e.g. FBE or 3LPE. However, larger surface area coupons can be used to assess d.c. stray current interference, refer to ISO/FDIS 22426 [44]

The ER probe element thickness typically varies generally from 250 microns to 1000 microns. The thicker the element the lower the sensitivity in terms of corrosion rate measurement. However, if a pipeline has an ongoing a.c/d.c. interference risk and corrosion is occurring then ER probes with a thinner element will exhibit a reduced life in comparison to the thicker element probes but will give corrosion rate to a higher degree of accuracy. Once the element thickness has been lost the coupon will have effectively failed.

Remote monitoring ER probes are available that can record, corrosion rate, remaining probe thickness, a.c. and d.c. current density, a.c and d.c. pipe to soil potential and coupon spread resistance. Data can be accessed remotely, and readings are typically taken at 1 to 2-hour intervals.

The ER devices can be solar powered, which gives the ability to take readings at regular intervals with an extended operational life. The ER probe devices should be capable of providing alarms in case of high rates of metal loss or significant positive pipe to soil potential excursions and alarm set points should be set to indicate possible detrimental levels of interference, The ER technique measures the change of the electrical resistance of a metal element formed as a coupon. When the metal element suffers metal loss due to corrosion the electrical resistance of the element will increase.

Since the resistance of the element also changes due to temperature variations, a second element, which is coated in order to protect it from corrosion is utilized for temperature compensation.

The element exposed to the corrosive environment constitutes the coupon part of the element, whereas the element protected from corrosion by the coating constitutes a reference element. The two are thermally connected in order to efficiently equalize any temperature difference between the two elements. The resistance values of the two individual elements are usually measured by passing an excitation current through the elements and measuring the voltage generated over the element length caused by the excitation current.

Wherever ER probes are installed they should be installed in accordance with the manufacturer's recommendations. It is important to ensure that the probes are compacted within graded soil close to the pipeline to ensure a spread resistance that reflects the resistivity of the local soil environment.

BS EN ISO 18086 provides detailed information on how ER probes operate, and the operating principles of ER probes are also described in BS EN ISO 21857.Figure G1 has been extracted from the latter standards.

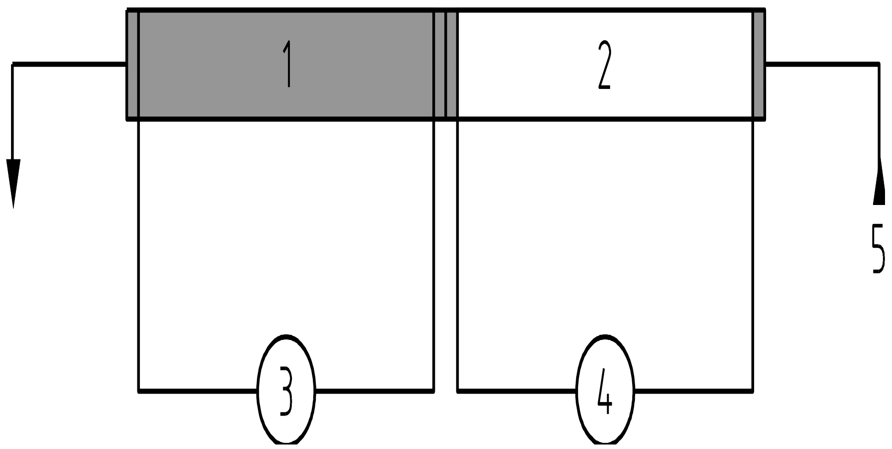

Figure G1 Schematic of ER Probe Construction refer to Table G1 for significance of values

Item	Parameter
1	reference element - Rr
2	coupon element – Rc
3	voltage across the reference element - VR
4	Voltage across coupon element VC
5	excitation current I_{exc}

Table G1 List of Parameters shown in Figure G1

ER probes can provide a direct read out of corrosion rate and some ER probes are also capable of remote monitoring. The thinner the probe element the shorter the probe life but the higher will be the accuracy to which corrosion rate measurements can be made.

Once the probe element of thickness generally between 250 to 1000 microns has corroded the ER probe will have effectively failed and would need to be replaced. It is essential than any ER probe used to monitor corrosion rates on cathodically protected pipelines is electrically connected to the pipeline.

Fast frequency analysis of ER probes provides a reliable measure of corrosion growth and even those results should be treated with caution as the probes need to be retro fitted and may not provide a fully accurate representation of the conditions at other locations on the pipeline in a given area,

G3 Corrosion Rate Assessment Methods

The measurement of anodic current density and duration at suitably sized coupons with data loggers will give an indication of the level of risk of d.c. corrosion and will provide an indication of the likely rate of corrosion that could be occurring on a pipeline system. However., it will not provide an accurate value for corrosion rate.

G3.1 Weight Loss Coupon Examination

One method of assessing the risk or magnitude of the d.c. corrosion rate on a pipeline is to carry out laboratory examination of a coupon that has been installed and connected to a pipeline to monitor a.c/d.c. current density. The coupon or a number of coupons can then be removed for laboratory examination at a later date to determine if any metal loss has occurred.

The disadvantage with coupons is that the instantaneous corrosion rate is not recorded only the average corrosion rate. This is because the metal loss is averaged over the time of installation but the coupon throughout its life may have been exposed to varying levels of d.c. current density and in some cases, corrosion may have only occurred in recent years.

Where a.c/ d.c. coupons have been installed on pipelines affected by d.c. interference then excavation and exposure of coupons for subsequent laboratory examination may be considered to ascertain the extent and nature of any metal loss or corrosion that has occurred. Ideally the coupons employed should be 1 cm^2 surface area coupons and examination can be used to assess the risk or magnitude of the d.c. corrosion rate on a pipeline. The method of assessment will be to carry out laboratory examination of a coupon that has been installed with ideally data available on the d.c. current density that the coupon has been exposed to and the variation in d.c. coupon to soil potential both ON and instant OFF value.

It is important to know the date of coupon installation and the coupon dimensions at the time of installation. The coupon can then be removed for laboratory examination to determine if any metal loss has occurred. The soil local to any coupon should be analysed in accordance with DIN 50929-3 [55] and coupon analysis carried out in accordance with BS EN ISO 8407 [56]

It is important that the soil analysis includes measurement of soil resistivity.

The analysis of coupons will help ascertain if there has been any ongoing corrosion on the pipeline system at similar sized coating defects in that area. It will assist in analysis of the level of corrosion risk particularly on pipelines or pipe systems that cannot be inspected by an inline inspection technique. The coupon analysis can be based upon metal loss or ideally 3D microscopy to gather accurate data on pit depths and determine rate of pitting attack.

G3.3 Inspection Vehicle Data

In line inspection (ILI) still remains an effective means of assessing whether a pipeline system is at risk of d.c. stray current corrosion and whether there is an ongoing risk. Operators should review the ILI frequency based upon the d.c. corrosion risk. On pipelines that are susceptible to d.c. interference then the ILI frequency should be assessed.

If detrimental levels of d.c. interference are present the ILI interval would generally be in excess of that normally adopted for a pipeline system, that is not affected by stray current interference.

If defect growth has been attributed to stray current corrosion, then the ILI frequency may need to be increased until it can be confirmed that the stray current corrosion risk has been mitigated. The MFL tool used should have sufficient sensitivity to detect the external metal loss features that would be likely to be produced from either a.c. or d.c. interference.

ILI has limitations when it comes to stray current corrosion as it is not particularly good at sizing relatively small deep defects. Likewise, the typical frequencies between ILI and the tolerance for metal loss (typically +/-10% to 15% for seamless pipe, which means that there is a widespread between possible corrosion rates.

ILI is poor when it comes to a.c. interference defects but defects from d.c. corrosion are typically larger Likewise, the typical frequencies between ILI and the tolerance for metal loss (typically +/-10% for seamless pipe means that there may be a widespread between possible corrosion rates.

When assessing the data from ILI runs and determining the risk of d.c. interference the tool sensitivity needs to be considered, as in line inspection may not identify some of the small defects attributable to d.c. interference. To provide an indication of accuracy operators should consider the typical POD for an ILI vehicle, assuming that it runs within the specified speed parameters. The POD is typically 90% i.e. it misses 10% of the features (including welds) of the 90% which are detected there is a 95% POI assuming the ILIV runs within the parameters specified thus 5% of the 90% may be incorrectly identified. Of the remaining defects only those that are above 5% are reported (thus the ILI could miss a small defect due to tolerance or report on a very small defect) assuming a repeat run can actually accurately identify the same defect.

The accuracy and reporting of defects should be confirmed with the ILI vendor to provide operators confidence in assessment of in line inspection results in determining a.c., d.c. or general corrosion risks.

The in-line inspection assessment should ascertain if there has been any growth in the smaller size defects. If there has been defect growth between successive pig runs, then this could indicate a risk of a.c. or d.c. interference corrosion and require further investigation. Operators may concentrate assessments on the larger metal loss feature growth rates, which can impact on the permissible MOP for the pipeline system and not take cognisance of growth in smaller dimension defects The rate of defect growth may also not be linear with time as the levels of d.c. interference may have changed between in line inspection intervals.

The growth assessments can be inaccurate if linear defect growth is assumed and an assessment of the possible variation in d.c. interference levels between inspection should be undertaken. If a pipeline is at risk of d.c. interference, then the ILI vendor should be advised so that they can assess any metal loss features that may be attributable to stray current