UKOPA
United Kingdom Onshore Pipeline Operators' Association

Technical Briefing Note

Electrical hazards on pipelines

UKOPA/TBN/005 Edition 1

October 2019

GUIDANCE ISSUED BY UKOPA:

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.

Comments, questions and enquiries about this publication should be directed to**:**

UK Onshore Pipeline Operators' Association
Pipeline Maintenance Centre
Ripley Road
Ambergate
Derbyshire
DE56 2FZ

E-mail: enquiries@ukopa.co.uk

Website: www.UKOPA.co.uk

Revision and change control history

Planned revision: 2024

Edition	Date	No. of pages	Summary of changes
1	October 2019	76	Final revision for use

Contents

1. EXECUTIVE SUMMARY

It is intended to provide guidance to pipeline operators on the electrical hazards that may occur on pipelines. It is intended to clarify and expand upon the information given in BS EN 50443 [1] and other international standards.

This TBN does not address the a.c. corrosion risks on pipelines as these are covered in BS EN ISO 18086 [2].and UKOPA/GPG/027 [3]. BS EN 15280 [4] provided guidance on a.c corrosion but has now been withdrawn. National Association of Corrosion Engineers (NACE) has recently published a document on a.c corrosion, namely NACE SP 21424 [5], which provides additional guidance.

This document provides information for pipeline operators on applicable standards and international practice. It gives guidance on how to minimise the safety risks on pipelines from a.c. interference from overhead or buried power cable systems together with those created by a.c. traction systems. The interference may occur as a result of inductive, capacitive or resistive coupling. Details of electrical hazards on pipelines from other sources e.g. electrostatic risks, lightning, electrically operated equipment and high frequency radiation are also identified.

This TBN addresses the electrical hazards associated with d.c. power sources on pipelines but does not cover d.c. stray current interference. Guidance on d.c. stray current interference is given in BS EN 50162 [6], which will be replaced in the near future by ISO 21857 [7].

The document covers the management of the electrical hazards on existing and new pipeline systems. It identifies various situations that could lead to risk, which operational personnel need to be aware of to ensure that appropriate mitigation measures are implemented.

Electrical interference on pipelines can result in safety and/or incendive ignition risks. It can affect operational personnel and, contractors working on pipelines when pipeline maintenance or construction activities are carried out. Electrical interference can under certain circumstances also provide a risk to the general public. This document aims to identify the risks and advise appropriate mitigation methods where applicable.

This TBN may not cover all risks and pipeline operators should conduct an evaluation of possible risks and hazards to have confidence that the electrical hazard risks on pipelines are as low as reasonably practical (ALARP).

2. INTRODUCTION

2.1 Background

This document has been prepared to provide operators with guidance on the requirements for the control and management of the electrical safety hazards on buried and above ground pipelines. These include new construction, modification and operational risks. The measures to be adopted in relation to evaluation of a.c. corrosion risk on buried pipelines are detailed in BS EN ISO 18086 and additional guidance is given in UKOPA/GPG/027. The protection criteria to mitigate a.c. corrosion risks are defined in BS EN ISO 18086. The latter document provides guidance on protection criteria and methods to mitigate and evaluate a.c. corrosion risk but does not provide detailed guidance on all aspects of a.c. interference. The safety aspects of a.c. interference from a.c. power lines and traction systems on pipelines are detailed in BS EN 50443 and are supplemented by the guidance given in this TBN and other international standards or publications e.g. AS/NZS 4853:2012 [8]. The Australian Pipeline Industry – “Guidelines for Electrical Hazards” Version 2 15/1/14. [9]. CAN/CSA-C22.3 No. 6-M91 [10] and NACE SP0177 [11]

This document is intended to provide information to pipeline operators, designers, managers and other relevant organisations on the requirements to minimize and manage the risk of electrical hazards on metallic pipelines. It is also aimed at providing guidance to developers, operators and promoters of new and existing power cable systems on the risks associated with the installation of power cables close to pipelines and the likely requirements that pipeline operators may have to reduce the risk to pipeline systems and personnel working on a pipeline. The different situations that can lead to risk are identified and appropriate mitigation methods, where applicable are described. This TBN should be reviewed by not only pipeline operations personnel but pipeline integrity and electrical engineers, as there is guidance given in this document that it is considered is not currently available in other UK standards or publications and operators should ensure that where new risks have been identified that appropriate action is taken.

2.2 Scope

The guidance in this document is applicable to all steel pipelines operated by UKOPA members and provides information on good practice for construction and maintenance. This TBN provides information on the electrical hazards that should be considered in certain specific situations to ensure all risks to the general public, operational personnel and pipeline systems during construction and operation are effectively managed. This TBN applies to both new and existing pipelines. Every effort has been made in the preparation of this document to identify relevant risks. However, some risks may not be included, and it is the duty of pipeline operators and owners to carry out their own assessment of situations that may lead to risk and implement appropriate mitigation methods.

2.3 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, 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

3. ELECTRICAL INTERFERENCE ISSUES ON PIPELINES

3.1 General

AC interference on both new and existing pipeline systems from crossing or parallelisms with overhead or buried power lines is a serious concern. There are two main issues associated with this phenomenon:

1) The electrical safety risk to pipeline personnel, sub-contractors working on a pipeline system and the general public, that arises if any contact is made to a pipeline or its above ground appurtenances, which includes CP test cables, at the time that there is short term or also long-term a.c. voltages present.

2) The a.c. corrosion risk on buried pipelines, which is a phenomenon that has been identified on cathodically protected pipelines. Problems arise where there are alternating currents, above defined limits, present on a pipeline; even if the cathodic protection levels are satisfactory and meet the criteria defined in BS EN 12954 [12], there can still be ongoing corrosion.

Note (This TBN will only address the electrical safety risks)

3.2 Coupling between pipelines and AC power sources

There are four different methods of coupling between a.c. power lines and pipelines:

a) Low frequency induction (LFI) arises due to the inductive coupling between long structures, e.g. between pipelines and power lines where they run parallel for some distance.

b) Capacitive coupling occurs due to the placing, temporarily or permanently, of above ground pipework / pipelines adjacent to high voltage overhead power lines. Capacitive coupling can also occur when pipelines and insulated power cables are in direct contact with each other.

c) Earth potential rise (EPR) occurs when current discharges from a power line cable to earth. Pipelines routed close to the voltage contour created by earth faults at pylons or substations can experience high touch potentials. Lightning can also be a source of EPR. A lightning strike on or near a pipeline / earth grid may cause EPR, or a flashover may occur if a pipeline is too close to a power line. These are examples of resistive coupling where current may flow through the air or soil to a pipeline.

d) Direct coupling can occur when a pipeline makes direct contact with a power source most likely during construction.

3.3 Safety issues

The primary safety issues in relation to a.c. interference from overhead and buried power lines on pipelines relate to the touch and step potential risks described in Section 4.0. However, other risks and hazards exist under certain circumstances and these are identified in this TBN.

Electrical safety risks should be considered during the pipeline route selection process, for routine monitoring surveys and for any work that will involve personnel coming in contact with a pipeline or any appurtenance for pipeline repair, construction, modification or inspection operations.

Induced voltages on pipeline systems can occur when pipelines are strung out close to overhead power lines during construction. The induced voltages created in such situations can affect personnel safety but also create problems for welding operations.

There may also be long line d.c. and a.c. currents in buried pipelines. Where long line currents exist, and a pipeline section is cut, then there may be a spark hazard at the discontinuity due to the disruption to the current flow.

Detailed guidance on electrical hazards associated with pipelines routed in close proximity to electrical power line systems is given in Sections 4.0 and 5.0 of this TBN. This TBN also incorporates some of the guidance given in international standards that is not at present provided by the UK or European pipeline industry in relation to electrical hazards and identifies a number of different situations that can result in electrical hazards and give rise to risk, which are not include in BS EN 50443.

The safety aspects associated with a.c. interference on pipelines is detailed in BS EN 50443.

3.4 Background information

This TBN provides details of reference publications related to a.c. interference and electrical hazards on pipelines in Section 8.0. There are a number of published standards and informative reference documents that are available and provide good guidance and advice on the topic of a.c. interference and electrical hazards on pipelines.

It is recommended that operators consult these documents to obtain additional guidance and information as appropriate. The reference documents include the Canadian Energy Pipeline Association "AC Interference Guideline Final Report - June 2014. [13], CIGRE TB 95 Guide on the influence of high voltage a.c. power systems on metallic pipelines [14], the INGAA Foundation Report [15] and Energy Institute Electrical Safety Code [16].

Appendix A of this TBN provides a list of the abbreviations and three letter acronyms used in this document, whilst Appendix B provides a list of definitions relevant to the contents of this TBN.

Appendix C includes guidance on the use of surge protection devices on pipelines. It is recognised that the UK gas pipeline industry does not routinely employ surge protection devices, but petroleum product pipeline operators do. This TBN therefore includes supplementary information on the nature of the surge protection devices employed, the situations where surge protection devices are used, the requirements listed in different standards with regard to the use of surge protection, the inspection requirements for surge protection devices together with a discussion on the advantages and disadvantages of surge protection and decoupling devices in specific situations.

4. ELECTRICAL SAFETY

4.1 Introduction

A.C. interference on new and existing pipeline systems from crossing or parallelisms with overhead or buried power lines is a serious concern. In addition to the a.c. corrosion risk, a.c. interference can result in electrical safety risks to a pipeline operator's personnel, contractors working on pipelines and the general public. Contact with a pipeline or its above ground appurtenances, during short term or long-term a.c. interference events, can result in an electrical shock risk if the voltage exceeds specified values

The BS EN standard that addresses a.c. interference on cathodically protected pipelines, namely BS EN ISO 18086 concentrates on the a.c. corrosion risk and specifically excludes the safety issues on pipelines from overhead and buried power lines or a.c. traction systems. BS EN ISO 18086 refers operators to National Standards and regulations and BS EN 50443 for relevant guidance on electrical safety issues.

However, whilst BS EN 50443 does give guidance on the topic of electrical safety, it should be noted that the latter standard does advise short term and long-term touch potential limits on pipelines that are higher than those currently accepted by the international pipeline industry and other organisations in the UK, e.g. electrical generating authorities, telecommunications organisations and the railway industries. BS EN 50443 also advises values for long-term touch potentials that are different to the values accepted by the International pipeline industry and do not comply with the Electricity at Work Regulations 1989 [17].and BS 7671 [18].

There is considered to be a need for harmonised guidance on touch potential risk on pipelines in the UK and if there is a concern in a specific situation about the magnitude of any touch potential risk or applicable criterion then expert advice should be sought.

Historically when pipelines were routed close to power lines designers did not give sufficient attention to the possibility of significant touch potentials being developed on pipelines installed close to pylons during fault conditions nor during long term operation. Thus, some pipeline operators in the UK may have locations where the pipe to pylon or pipe to substation separation distance is insufficient to ensure that any touch potential developed on a pipeline during fault conditions does not exceed safe limits.

There is often a limited awareness of the electrical safety risks to personnel involved in day to day operations and/or construction activities on pipelines by pipeline operators. To date, it is believed that there have not been any significant known reported incidents in relation to electrical safety or shock on pipelines in the UK, but this does not mean that pipeline operators should not consider the electrical safety risks when carrying out works. Pipeline operators should ensure that the electrical safety risks are effectively managed. If an incident was to occur in certain situations, it could have potentially fatal consequences.

The electrical safety risks to personnel should be identified in any design and construction risk register produced under the Construction (Design and Management) Regulations 2015 [19]. This would apply to work associated with the design, construction and modification of any pipeline system, the residual risks that exist following construction and or modification to a pipeline system should be identified by the designer together with appropriate mitigation. Sufficient information should be provided to the pipeline operator post construction to enable any residual risks associated with electrical hazards to be controlled.

4.2 Training and awareness

Pipeline Operators should ensure that personnel and-contractors working on pipelines are aware of the electrical safety risks on pipelines routed close to power lines. This can be achieved by the provision of suitable training to personnel that operate and maintain pipelines, tool box talks and the development of safe working procedures.

Personnel should be aware that work on pipelines should cease when there is a lightning or storm risk, that there are personnel protective equipment requirements in certain situations that should be adopted to reduce risk and specifications that apply to electrical test equipment when carrying out testing on pipelines e.g. routine measurement of pipe to soil potentials or conducting over the line surveys. The risks to personnel working on pipelines from lightning are discussed in detail in Section 4.14.

Lightning activity or high voltage power line faults many kilometres away can result in a hazardous voltage being created on a pipeline some distance from the voltage surge location. It is not possible to predict when such events will occur. They will be relatively rare, but the consequences for personnel in contact with a pipeline can be potentially fatal. Thus, limiting contact times with a pipeline is important as is ensuring appropriate training to personnel is provided.

Pipeline operators should identify high risk locations where a significant touch potential risk may exist e.g. close proximity of a pylon, pylons or electrical substations to a pipeline or in specific geographical locations. Maps are available showing lightning hot spots, there are also other online daily resources available to show the risk every day or hourly, etc. (https://www.netweather.tv/live-weather/lightning)

4.3 Short term a.c interference

Short term interference is the voltage that can be created on a pipeline from a phase to earth or phase to phase fault in an overhead power line at a pylon in close proximity to a pipeline, at an electrical substation or from lightning strikes. Short term interference events are relatively rare, typically once every 5 to 10 years and will only exist for a short period of time before the protective devices on the power lines operate. The disconnection time is typically within 200ms for 132 to 400kV circuits and may up to 1 second for up to 33 kV circuits. BS EN 50522 [20] indicates that in a major substation there will typically be a short duration phase to earth fault every 5 years. The Australian Pipeline Industry Electrical Hazards Guidelines advise that "In *Australia, power lines are well maintained and the probability electric shock from LFI / EPR is low (1-2 faults per annum of up to 1 sec duration per 10km of exposure)*".

Short term interference events generally occur as a result of spurious faults with lightning, bad weather and bird strikes, generally accounting for ~80% of OHL power frequency faults. They would relate to periods of time less than 3 seconds [21]

It should be noted that when a fault occurs a HV power system may automatically re-energise as the fault current often clears the original cause of the fault e.g. a bird strike or vegetation caught in insulators. Automatic re-energisation of a power line system then generally occurs another two times before the circuit will remain isolated once it is clear that there is a short circuit. The process of automatic re-energisation is called Delayed Auto Reclose (DAR). The re-energisation occurs in milliseconds and the protective devices try to reclose three times normally, but different circuits have different disconnection times and a number of re-closures occur before finally remaining isolated.

Short term interference effects create a higher touch potential voltage than in the long-term interference case, but the voltage excursions are present for shorter durations. The current level the body can accommodate is related to the time of exposure and in terms of risk the current values that a defined percentage of the population can withstand are considered when determining voltage limits.

In order to reduce the risk to personnel the time in contact with a pipeline or above ground appurtenances does need to be limited and personnel need to be made aware of this. The current path should also be as high a resistance as possible e.g. hand to foot rather than a lower resistance path e.g. hand to knee or hand to hand

4.4 Long term a.c. interference

Long term interference can result in a.c. voltages in the region of 100V present at some CP posts on buried pipelines that are routed in close proximity to high voltage overhead power lines for appreciable distances under certain extreme conditions. The a.c. voltage levels observed in practice are generally much lower than 100V, but they can exceed 15Vrms in certain circumstances on some pipelines. The long-term voltage is due to inductive coupling between pipelines and power lines but when changes in the power system operation occur e.g. one circuit of a two-power circuit system is off for maintenance or repair or the loading on power line circuits is unbalanced then levels of touch potential in excess of safe values that may not have been experienced in the past can occur.

The touch potential risk on pipelines routed close to power lines that may exist in normal operation is termed the long-term touch potential risk and is the voltage induced on the pipeline from the inductive coupling between a pipeline and power lines routed close to each other. The magnitude of induced a.c. voltage is primarily related to the length of parallelism, separation distance between power line and pipeline, power line voltage and power line load.

Long term interference events occur for periods of time in excess of 3 seconds and the voltage present on a pipeline from LFI would exist for the period of time that the power circuit is operating and would generally be in excess of 24 hours. It would vary during the course of a day as the power line load changes.

4.5 Touch potential

A touch potential is the voltage between the energized object and the feet of a person in contact with the object (see Figure 1). In the case of pipelines, it is the voltage between the pipeline and the feet of anyone making electrical contact with the pipeline, who is in contact with the ground.

There may also be a touch potential risk between an operative’s hand in contact with the pipeline and another earthed object. This will result in current flow from hand to hand rather than from hand to feet during a fault condition. There may also be a current flow from hand to knee for example when taking a CP reading on a pipeline, where an operative may kneel to access a test facility

The (effective) touch voltage Ute is defined as *“The voltage between conductive parts when touched simultaneously by a person or an animal*

NOTE 1 The value of the effective touch voltage can be appreciably influenced by the impedance of the person or the animal in electric contact with these conductive parts

NOTE 2 The conductive path through the body is conventionally from hand to both feet (horizontal distance of 1 m) or from hand to hand "

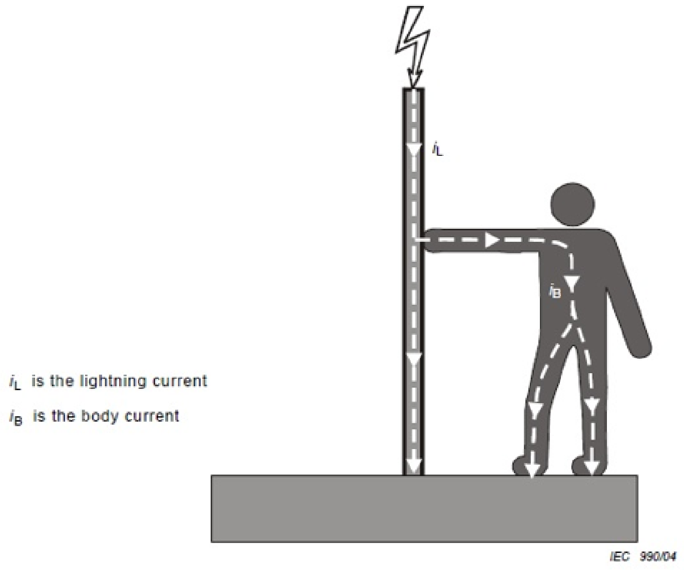


Figure 1 Pictorial representation of touch potential extracted from BS EN 50522

The current flow direction through different parts of the body and the effect on the heart is detailed in PD IEC TS 60479-1 [22] and the effects as a result of lightning strokes is detailed in PD IEC TS 60479-4 [23]. The values of current flow in the latter documents have been used to determine the permissible voltage limits in BS EN 50443 and other standards.

The magnitude of the a.c. current flow through the human body is related to the body impedance, the current path, contact area and the touch voltage. The body impedance decreases as the voltage level increases.

PD IEC 60749-1. advises that the effect on the human body is related to current magnitude and the duration of the current flow. The body impedance or resistance to current flow is also dependent upon the voltage magnitude. The higher the voltage the lower body impedance will be. The body impedance also varies across the population as well e.g. at 200V 5% of population will have impedance of 3,500 ohms but for 95% of population it will be 8,650 Ohms for wet conditions hand to hand low contact. Indeed, for dry conditions at 25V the body impedance is 11,125 ohms but at 200V it is 1,375 ohms for medium contact hand to hand.

PD IEC 60749-1 provides information on the effect of the magnitude of current flow through the body and the duration and subdivides this into different zones as indicated on Figure 2, whilst Figure 3 also extracted from PD IEC 60749 shows the effect of a.c current in the 15 to 100 Hz frequency range on persons for left hand to feet contact.

On pipelines CP test posts each side of I/Fs and I/Js are effectively connected to different earthed structures and should be separated by at least 3m to mitigate the touch potential risk.

No bare pipe should be accessible each side of I/F or I/Js to prevent personnel contact so that contact cannot be made with different earthed structures, since if there is EPR event on one structure this could create a touch potential risk. The dielectric strength of the protective coating system should also be considered e.g. where metallic based paints are used as they can facilitate electrical contact with the pipe.

Zones	Boundaries	Physiological effects
AC-1	Up to 0,5 mA curve a	Perception possible but usually no 'startled' reaction
AC-2	0,5 mA up to curve b	Perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects
AC-3	Curve b and above	Strong involuntary muscular contractions. Difficulty in breathing. Reversible disturbances of heart function. Immobilization may occur. Effects increasing with current magnitude. Usually no organic damage to be expected
AC-4 [1]	Above curve c_1	Patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time
	c_1-c_2	AC-4.1 Probability of ventricular fibrillation increasing up to about 5 %
	c_2-c_3	AC-4.2 Probability of ventricular fibrillation up to about 50 %
	Beyond curve c_3	AC-4.3 Probability of ventricular fibrillation above 50 %

[1] For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to feet. For other current paths, the heart current factor has to be considered.

Figure 2 Time current zones extracted from PD IEC 60749-1 on the human body.

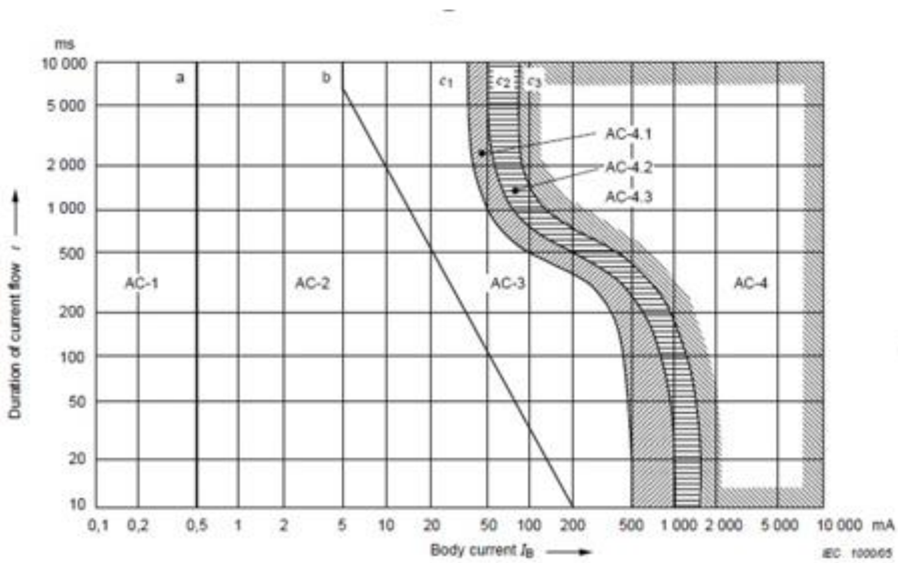


Figure 3 Effect of magnitude of current versus duration for different current classification zones indicated on Figure 2

4.6 Step potential

The step potential is the voltage difference across the ground that would occur when fault current flows (see Figure 4). The closer the person is to an overhead a.c. power cable pylon during a fault condition the greater the soil surface voltage field over a specified distance. A step potential is the voltage between the feet of a person standing near an energized grounded object. Figure 4 provides a schematic representation of a step potential situation and is extracted from BS EN 50522.

It is equal to the difference in voltage, given by the voltage distribution curve, between two points at different distances from the electrode. A person could be at risk of injury during a fault simply by standing near the grounding point.

The step potential is defined as the voltage between two points on the earth's surface that are 1 m distant from each other, while a person is contacting them.

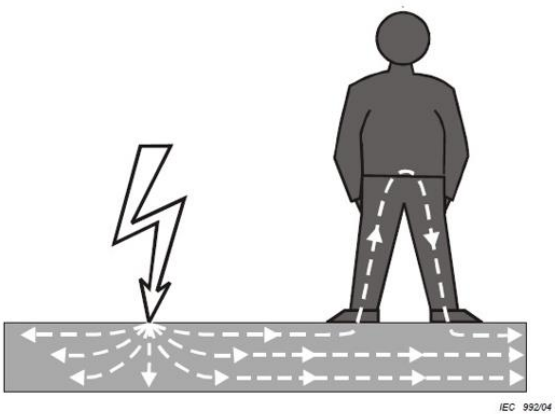


Figure 4 Pictorial representation step potential extracted from BS EN 50522

In the case of pipelines, step potential risks would occur during fault conditions when personnel are surveying pipelines, working close to overhead pylons or substations, or when carrying out operations near any a.c. mitigation system earth electrodes or CP system groundbeds.

Personnel working near CP groundbeds may be affected by a touch and step potential risk as groundbeds can act as earths to discharge a.c. or lightning fault currents from pipelines.

4.7 Long-term AC pipe to soil potential voltage limit on pipelines

Prior to a.c. corrosion being identified on a pipeline in the UK in 1999, the maximum permitted a.c. voltage on a pipeline system was generally taken to be 15V rms by the UK pipeline industry and that voltage limit was based upon the guidance given in the previous editions of NACE SP 0177, which limited the maximum a.c. voltage on a pipeline to 15V rms.

Canadian Standard CSA –C22.3 states that the maximum acceptable touch potential on a pipeline should be 15V rms and at voltages above this value then the pipeline system should be grounded. The latter standard advises that other industries do accept higher voltages but that for pipelines the maximum voltage should be 15Vrms and that is generally the internationally accepted limit. One reason the 15V rms limit was applied is because CP test post potential measurements are not carried out on a frequent basis and the a.c. voltage present on a pipeline may vary over time. Thus, if 15Vrms is recorded at one instance in time the a.c. voltage on a pipeline at a given CP test facility could be higher at other times. Measurement of voltages of 15V rms or greater would indicate that action would be required to investigate the risk, as the voltage levels could exceed safe limits at other times.

The Canadian Energy Pipeline Association report [13] states "*The shock hazard arising from induced a.c. has been widely recognized for many years in North America, where the NACE SP0177 standard stipulates that an AC voltage of 15 V or greater between a pipeline appurtenance and ground, which could expose a person to a touch voltage, is considered a shock hazard.*

This requires that the touch voltage be reduced to a safe level or the pipeline be treated as a live electrical conductor. The 15V limit was determined by multiplying 15 mA, (considered the current limit below which a person could let go when grasping an electrified conductor), and 1000 Ohm, (conservatively considered the human body impedance assuming a contact resistance of zero ohms).

In Europe the Canadian Energy Pipeline Association state that the touch voltage limit is typically 50V before remedial action is required" the latter statement in relation to Europe relates to the guidance in CIGRE TB 95. However, the CIGRE TB 95 limit does not relate to the practices that have been generally adopted in the UK where the 15V rms limit has often been considered by pipeline operators in the past to be the safe limit based upon international guidance. It is accepted that touch potentials less than 50V rms should not provide a significant electric shock risk to personnel, but they may result in involuntary actions e.g. slips, trips or falls, which could lead to injury.

Indeed, if a member of the general public was to complain that they had experienced an electrical shock off a CP post stud for example, it may be difficult to prove that the value was within safe limits therefore the use of as low a value as practical for a.c. touch potential seems sensible.

The 15V rms limit has generally, within the UK pipeline industry been considered as the maximum a.c. voltage level to aim for in regard to electrical safety on pipelines and it is the safe touch potential voltage value on pipelines that is advised in this TBN.

BS EN ISO 18086 recommends that the maximum voltage on a pipeline should be limited to 15Vrms to mitigate the risk of a.c. corrosion. Thus, whilst a.c. voltages slightly in excess of 15V rms may not pose a safety risk to personnel, if voltages in excess of 15V rms are permitted on pipelines then this would expose pipelines to an a.c. corrosion risk.

In addition, if a.c. voltages are present on a pipeline system they can be rectified by the conventional variance-controlled CP T/R units that are commonly employed on UK pipeline systems. This will produce an undesirable fluctuating d.c. current output from CP T/R units.

The rectification of induced a.c voltage on pipelines by some T/R units can occur at voltage levels above approximately 2 to 3Vrms and could result in varying d.c. pipe to soil potentials due to the additional d.c. current output provided from CP TR units, as a result of rectification of the variable long-term a.c interference induced on a pipeline.

A fluctuating d.c. current from a T/R unit means control of the levels of d.c. pipe to soil potential on a pipeline system may be difficult with high a.c voltages present, and this can result in under and overprotection.

The use of switch mode d.c. power supplies can mitigate this risk i.e. a fluctuating d.c. current output when an a.c. voltage is present on a pipeline. One other method of controlling the risk is to include a choke or inductance in the negative connection to the T/R unit d.c. output to reduce the a.c voltage level seen by the T/R unit rectifier bridge.

Significant levels of a.c. interference on pipelines can also affect the ability of pipeline location equipment to accurately locate pipelines and record depth measurements due to electrical noise. Furthermore, if significant levels of a.c interference are present on pipelines these can affect the ability of CP monitoring and over the line survey equipment to record accurate d.c. pipe to soil potentials. Indeed, if the a.c. rejection capability of CIP survey data logger monitoring equipment is not sufficient to filter the a.c voltage present this can lead to erroneous CIP survey indications, particularly close to overhead power lines.

All test equipment must be able to record true rms values. In the UK a high voltage system is one where the a.c voltage exceeds 1000V, a low voltage system is one where the a.c. voltage is between 50V to 1000V and Safe Extra Low Voltage (SELV) is where the a.c. voltage is less than 50V. The maximum long-term touch potential for periods of time >3s permitted in BS EN 50443 is 60V, in BS EN 50222 the maximum limit is 85V, whilst in BS EN 50122-1[24] it is 60V for periods of time greater than 300 seconds.

However, if a long-term voltage above 50Vrms was present on a pipeline in the UK this would make the pipeline system a low voltage electrical system i.e. between 50 to 1000V in accordance with BS 7671. Thus, the maximum permissible long-term voltage on pipelines should be less than 50V to prevent a pipeline being classed as a low voltage conductor.

The only standard that considers risks associated with involuntary movement from the 'startle' effect is BS EN 50122-1 which places a touch voltage limit of 25 V for workshops and where the general public may come into contact with an earthed structure [25]. This voltage coincides with that given in BS 7671 for un-insulated live parts that can be touched. It also coincides with the 25 V limit in BS 7430 [26] where there are no recommendations for earthing and bonding. In the case of pipelines there may be equipment connected to the pipeline which is positioned such that a 'startle' reaction could lead to a risk, other than a fatal electric shock. There are also pipeline appurtenances that could be touched by the general public and where the general public are exposed to risk and lower permissible voltages less than 25V should be considered.

Thus, whilst it is clear in BS EN ISO 18086 that the 15V limit should apply to mitigation of a.c. corrosion risk it is considered that the same limit should also apply to safety and pipeline operability. There should not be two different a.c. voltage limits on the same structure. In relation to this TBN it is considered advisable to reduce the a.c pipeline to soil potential to as low a value as possible. Thus, the a.c. voltage value recorded during routine monitoring should not exceed 15V rms for safety, the control of a.c corrosion, ensuring a stable d.c. pipe to soil potential and ability to conduct over the line surveys. The a.c voltage on a pipeline may need to be considerably lower than 15Vrms at certain locations to reduce the a.c corrosion risk to an acceptable level, if the pipeline system is deemed to be at risk of a.c. corrosion.

4.8 Short term touch potential limits

BS EN 50443 does permit short-term voltages on pipelines, with values up to 1,500V for faults of duration less than 200ms. However, BS EN 50443 states that the latter voltages are applicable to personnel that are electrically instructed and the contact resistance to earth for personnel exposed to the hazard is greater than 3,000 ohms.

The latter contact resistance may not be readily achievable by personnel working on cross country pipelines. This is evident from the body impedance values given in PD IEC/TS 60479-1 where considerably lower values for body impedance are quoted for the typical environmental conditions associated with pipelines. The short-term voltage levels that can be accepted on buried utilities are also detailed in ENA TS 41-24 [27]. and for a buried pipeline should be less than 650V for a fault that is cleared within 200ms.

PD IEC/TR 60479-4 details the effect that a.c current will have on the human body. The latter standard does not define the voltage limits but shows that the body impedance varies depend upon the environmental conditions and touch voltage level that personnel are exposed to.

The magnitude of current that the human body can withstand is dependent upon the fault duration.

BS EN 50122-1 does give guidance on touch potential risk and that is similar to the guidance given in ENA TS-41-24 but different to the guidance in BS EN 50443.

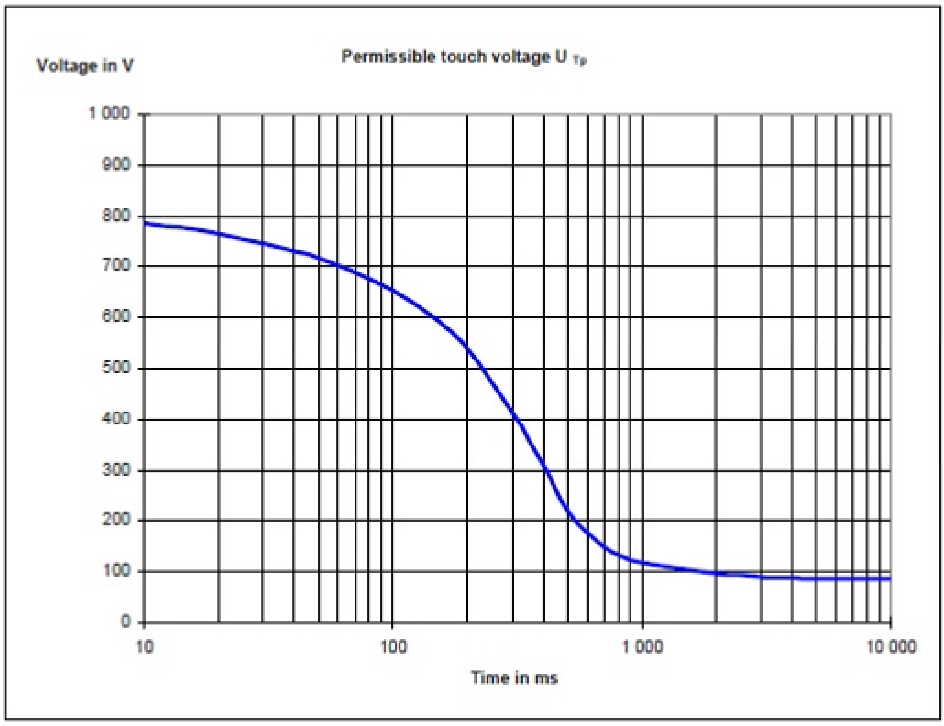
Figure 4 in BS EN 50522 given as Figure 5 in this TBN shows the variation in touch potential with disconnection time for the protective device. Figure 5 is based only on bare hand to hand or hand to feet contact. It is allowable to use the calculations given in Annex A of BS EN 50522 to take account of additional resistances e.g. footwear, superficial high resistivity materials to increase contact resistance.

Figure B.2 in BS EN 50522 given as Figure 6 in this TBN shows how the touch potential limit varies with contact resistance.

The maximum touch potential limit does vary dependent upon the standard selected, with higher touch potential limits given in BS EN 50443 and BS EN 50552 than BS EN 50122-1.

BS EN 50522 gives a maximum touch potential limit for a disconnection time of less than 200ms of 1,570V, BS EN 50443 a limit of 1,500V for a similar disconnection time, whilst BS EN 50122-1 gives a value of 645V and ENA TS 41-24 and maximum touch potential limit of 650V for a similar disconnection time.

However, when the working conditions on pipelines are considered e.g. personnel are often not electrically instructed, lone working is carried out, working conditions are frequently wet, there may be excessive vegetation present and possible hand to knee contact. It is recommended, in this TBN, that touch potential limits given in BS EN 50122-1 should be adopted for short term interference situations of 1 second or less.



Fi

NOTE For duration of current flow considerably longer than 10 s a value of 80 V may be used as permissible touch voltage U_{Tp}.

Figure 5 Permissible touch potential versus time from BS EN 50552 for low contact resistance.

BS EN 50122-1 applies to the railway industry and parts of a railway electrical installation are accessible to the general public and can be linked to the traction return system. These include equipment at level crossings and enclosures for signalling and other systems on platforms.

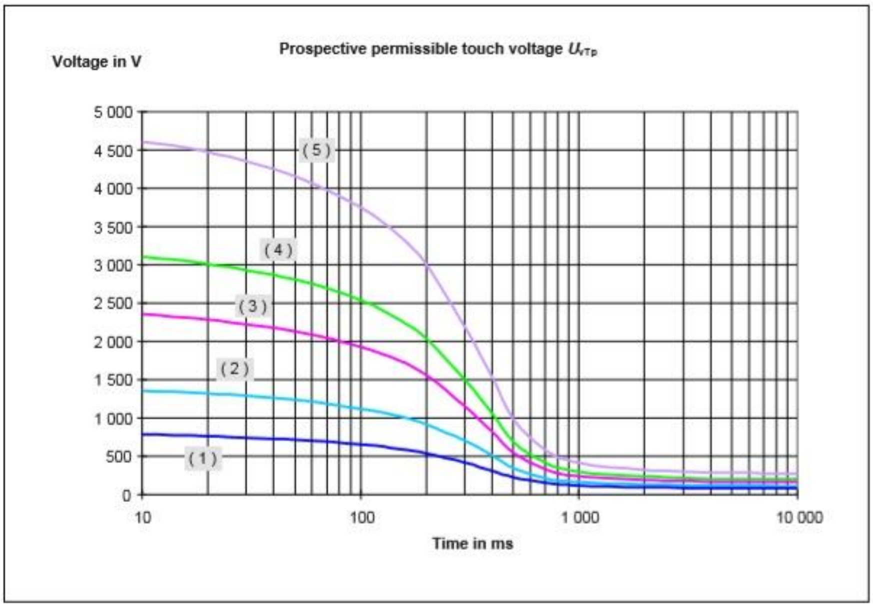
Hence consideration has been given in the latter standard to the requirements relating to touch voltages for traction systems as these voltages can appear on equipment that is not related to traction systems.

The touch voltage limits given in BS EN 50122-1 are derived from PD IEC/TR 60479-1 in the same manner as those given in BS EN 50522 but with several different assumptions.

The long-term touch potential limit given in BS EN 50122-1 of 60V is consistent with the values given in BS EN 50443 and BS EN 50522 in terms of safety. The touch voltage values given in BS EN 50122-1, for railway installations, include the recommended allowance for footwear and are based on a 0% risk of ventricular fibrillation. They are also intended for outdoor situations where the general public may have access and where there is a mixed workforce, many of whom will not be ‘electrically instructed’

The voltage limits in BS EN 50443 are based upon the current required to cause ventricular fibrillation on 5% of the population.

Because of the similarities between the conditions considered in the railway standard and those that are expected to apply to exposed equipment on a pipeline it is recommended that the touch voltage limits given for fault conditions in BS EN 50122-1 are adopted as limits in any analysis carried out for new pipelines.



(1):	Permissible touch voltage according Figure 4			
(2):	R_F = 750 Ω	(R_{F1} = 0 Ω,	ρ_s =	500 Ωm)
(3):	R_F = 1 750 Ω	(R_{F1} = 1 000 Ω,	ρ_s =	500 Ωm)
(4):	R_F = 2 500 Ω	(R_{F1} = 1 000 Ω,	ρ_s =	1 000 Ωm)
(5):	R_F = 4 000 Ω	(R_{F1} = 1 000 Ω,	ρ_s =	2 000 Ωm)

NOTE R_{F1} = 1 000 Ω represents an average value for old and wet shoes. Higher values of footwear resistance may be used where appropriate.

Figure 6 Touch potential versus time from BS EN 50552 for different contact resistances.

As stated in this section of the TBN, it is considered that the safe touch potential limit that should be applied on pipelines is 15V rms, whilst it is accepted that personnel exposed to long term voltages that are less than 25V would be safe, voltages in the region of 60V rather than pose a fatal shock risk could still result in involuntary action, leading to injury.

It is considered that in the case of new pipelines or where new power systems, or substations are constructed close to pipelines that the guidance given in BS EN 50122-1 should be followed in relation to permissible touch potential limits.

However, on existing pipelines there will be locations on existing pipelines where it will not be practical or possible to achieve the short-term touch potential limits detailed in BS EN 50122-1. In such cases the touch potential limits detailed in BS EN 50443 would need to be adopted and operators should review the values selected with a competent body.

There will be a number of situations on existing pipelines operated by UKOPA members where it will not be possible to obtain the touch potential limits specified in BS EN 50122-1 simply because pipelines and power lines are located too close to each other. In such cases higher permissible touch potentials may be accepted provided appropriate risk mitigation methods are in place and the limits are based upon the guidance given BS EN 50443. It should be noted that at some locations where pipelines are routed very close to pylons the short-term voltage levels during fault conditions may exceed the safe limits proposed in BS EN 50443 and pose a possibly fatal electrical shock risk.

Expert advice should be sought in such situations.

The touch voltages given in BS EN 50122-1 are reproduced on Table 1

Power system fault duration time (seconds)	BS EN 50122-1 safe voltage limit (Volts)
0.02	865
0.05	835
0.1	785
0.2	645
0,3	480
0,4	295
0,5	220
0,6	180
<0.7	155
0.7	90
0.8	85
0.9	80
1.0	75
300	65
>300	60

Table 1 Summary of acceptable touch potentials from BS EN 50122-1

The touch voltage limits for different protective device disconnection times are given in BS EN 50443 and are reproduced on Table 2

Power system fault duration time (seconds)	BS EN 50443 safe voltage limit (Volts)
t ≤ 0.1	2000
0.1 < t ≤ 0.2	1500
0.2 < t ≤ 0.35	1000
0.35 < t ≤ 0.5	650
0.5 < t ≤ 1.0	430
1.0 < t ≤ 3	150
>3.0	60

Table 2 Summary of acceptable touch potentials from BS EN 50443

4.9 Buried power cables and touch potential risks

Buried HV cables are often now used for new power transmission systems. In such cases they may cross existing pipelines or be routed in parallel with them for some distance.

The cable crossing should ideally be at right angles and should be at a clearance of at least 0.6m below the pipeline and preferably 1.0m. Cable crossings below pipelines are preferred since if there is ever a requirement in the future to expose the pipeline at that crossing location then there will be a lower risk of cable damage. However, where crossing below a pipeline may not be practical it is possible to cross above a pipeline provided the 0.6m clearance is maintained and the cable depth at the crossing location meets with the power operators' requirements.

In the past barriers have been created in terms of using high dielectric strength materials such as rubber matting to reduce risks or interactions.

This may still be utilised where the crossing is below the pipeline and where the extent of the matting is not significant to prevent CP current from reaching the pipeline or the pipeline to be shielded from the CP current. Likewise, the use of matting above the pipeline is now discouraged as it can render CIPs measurements ineffective particularly where the matting is extensive

Acute cable and pipeline crossings with HV buried cables should be avoided to minimise the induced voltage levels. This applies to crossing angles less than 45 degrees. High dielectric strength polymeric barrier material should be considered to limit inadvertent contact between the power cable and pipeline and where employed should be placed at the midpoint between the two services.

No bare earth conductor should be routed with the power cables and cross a pipeline or be installed within the pipeline wayleave or in a location close to a pipeline that would create a hazardous touch potential on a pipeline during fault conditions.

Power cables should be routed in suitable ducting at the pipeline crossing point and within the pipeline wayleave and cable warning tape or preferably cable tiles laid 150mm above the cable.

Cables shall not contact a pipeline or capacitive coupling could occur.

Buried HV cable systems will be joined at joint bays along the cable system route. Not all joint bays may have an earth associated with them. Thus, joint bays without an earth should not pose a touch potential risk to a pipeline system during a fault condition. However, at joint bays where there is an earth installed, then during fault conditions the local joint bay earth potential rise could pose a risk to any pipeline in the vicinity, as it might create a high touch potential.

Joint bays on buried HV cables should be located as far away as practical from a pipeline system to ensure that the pipeline is not affected by high ground potential rises during a fault condition. The protective devices provided on the HV cable system should have a disconnection that will ensure that the touch potential on a pipeline will be less than values specified in BS EN 50122-1 for the disconnection time of the protective device.

In the case of HVDC cable systems the touch potential limits should comply with voltages limits stated in Table 5 of BS EN 50112-1. The maximum long term d.c. voltage limit is less than 120V and for protection device disconnection time of less than 0.2 seconds it is 285V.

During fault conditions on HVDC cable systems any fault current picked up by a pipeline can result in high rates of corrosion within a short period of time and the latter effect must be considered in relation to HVDC power cable systems. For guidance on d.c. stray current interference effects refer to the guidance in ISO 21857.

The GPR at each joint bay on a HVAC cable system within 50m of a pipeline should be determined to ensure that the pipeline is not exposed to a hazardous touch potential If any joint bays are outside the 50m separation distance it is recommended that the cable operator provides information to the pipeline operator on the GPR for the joint bays closest to the pipeline and confirms the maximum touch potential that may arise on a pipeline. CIGRÉ TB 347[68] provides information on calculation of earth potential rises on screened cable systems.

BS EN 50443 advises that in respect to possible induced long term a.c. interference risks only those cables within 50m of a pipeline system should be considered.

Low voltage cable systems e.g. 11kV or below generally do not create any significant levels of induction. However, whilst voltage levels above 11kV generally do not create significant issues in relation to a.c. interference in relation to higher voltage buried power cable systems long term induced voltages can be created on a pipeline and result in an a.c. corrosion risk.

Each individual case where a buried power cable is routed close to or crosses a pipeline should be looked at and studied based upon merit and expert advice sought.

The power cable construction arrangement, separation distance between each cable phase and pipeline, whether there are any phase transpositions along the cable route and the mutual inductance between cable and pipeline all need to be considered to assess the induced voltage levels. If all phases of a power cable system are routed in a common duct, then that will create lower levels of a.c. interference than situations where each phase of the power cable system is routed in a separate duct.

4.10 Operational safety issues

The safety issues in relation to a.c. interference from overhead power lines on buried pipelines generally relate to the touch and step potential risks to pipeline operators’ personnel, contractors working on behalf of the operator and the general public.

It is important that pipeline operations personnel are aware of these risks. It is also important to note that in the case of the case of step potential risks these will be at the greatest close to the power line pylons, where the highest voltage field gradient will exist during a fault condition.

Thus, personnel should take care when carrying out over the line surveys and limit time spent close to power line pylons and wear insulating footwear. In making test connections for electrical measurements for routine CP measurements on pipelines whether subject to a.c. interference or not, all test leads, clips, and terminals should be properly insulated, fused and comply with the requirements of GS 38 [28]. The test equipment should comply with requirements of BS EN 61010-1[29].

When taking pipe to soil potential readings on pipelines the reference electrode should be placed in the ground first before the structure connection is made. Personnel should ensure that the meter is set to the correct range for the measurement that is required to prevent damage to test equipment. On completion of the measurement the structure connection should be removed first. The latter steps are required to ensure safety of personnel and that in the event of a voltage surge there is a current discharge path to reduce the voltage that operations personnel are exposed to.

Leads should be connected to the test instruments before making connections to the structure, clips are preferred to probes. When each test is completed, the connections shall be removed from the structure before removing the lead connection from the instrument. All test connections must be made on a step-by-step basis, one at a time.

Operational maintenance on overhead power line circuits, where one circuit of a two-circuit power cable system is taken out of service can result in higher levels of touch potential than would be experienced if the power line was operating with both circuits in operation. Personnel involved in routine CP monitoring should be made aware of this risk.

If a sudden increase in long term a.c. interference on a pipeline was observed, it could be associated with a change in the operational conditions of adjacent HV power lines. It is therefore important to record a.c. voltages on pipelines as part of routine CP system monitoring checks and if any sudden changes are observed then the power cable operators should be contacted to identify if there have been any changes in the power line load or operation.

CP maintenance personnel should be instructed to report to their line managers any increase in a.c. interference that is observed on a pipeline system during routine monitoring, as that may be indicative of a change in the configuration of overhead powerlines or increase in the operating load.

4.11 Pipeline construction near power lines

The safety issues in relation to pipeline construction near overhead and buried power lines should be considered by the designers of pipeline systems, pipeline operators and installation contractors to ensure that adequate separation is maintained between the pipeline and any overhead or buried power source and all electrical safety and mechanical damage risks are mitigated. The ability to access pipelines following construction for maintenance activities shall be considered where new power lines are constructed.

Where new cables are installed close to pipelines then drawings should be updated to identify the new risk.

Buried power cables need to be considered as part of the safety assessment process and utility searches using Linesearch or similar organisations should be carried out prior to any excavation work being carried out to establish if there any power cables installed within the pipeline wayleave or designated work area. In the case of buried HV power cables >33kV the search needs to be extended to determine if there are any cables within 50m of the pipeline and ascertain if there any parallelisms between the buried cables and pipelines.

It should be noted that the level of long term a.c. interference from buried cables is a lot lower than from overhead HV cables. It is generally within acceptable limits provided sufficient separation is achieved between the two systems. However, on high load buried power cable systems these can increase the a.c. voltage on a pipeline to by a sufficient amount to increase the a.c. corrosion risk even though the level of induced voltage may not exceed the required safety limit.

Guidance on avoidance of damage to buried services is given in HSG 47 [30] and guidance on avoidance of danger from overhead power cables is given in GS 6 [31]. CAT scan surveys should be conducted to identify the presence of any buried cables.

GS 6 states *"The guidance is for people who may be planning to work near overhead lines where there is a risk of contact with the wires and describes the steps you should take to prevent contact with them. It is primarily aimed at employers and employees who are supervising or in control of work near live overhead lines, but it will also be useful for those who are carrying out the work".* GS 6 identifies the statutory regulations applicable to work in the vicinity of powerlines and the responsibilities and duties of anyone undertaking work within 10m of an overhead power line.

It is important that prior to commencement of any work on a pipeline that would involve plant and equipment crossing near or underneath overhead power cables that the power system operator is notified, and the guidance given in GS 6 is followed. Any specific power line operator safe working procedures for work within the vicinity of overhead power lines should be established and followed.

The safe personnel separation distance from power lines may be different to that for plant and equipment and will be dependent upon the power cable operating voltage. Information on safe clearance distances and guidance on carrying out work near overhead power conductors is given in ENA TS-43-8 [32].

ENA TS-43-8 gives guidance on safe distances in different cases and the minimum horizontal distance from overhead power cables at which protective barriers should be located at crossing points. It is important that contractors working on new pipeline construction projects or on repairs/modifications to existing pipelines comply with the cable operator codes of practices and safe working distances plus all relevant ENA guidelines.

Figure 7 extracted from GS 6 shows the typical arrangement at an overhead powerline crossing.

The clearance distance is determined by the power line operating voltage. Table 3 extracted from ENA TS-43-8 provides typical guidance. For overhead power cables personnel can be exposed to an electrical shock risk without even touching a cable as current can arc across. The minimum distance for separation between cables and personnel for a 400kV system is 3.1m for a 132kV system it reduces to 1.4m.

Description of clearance	Nominal system voltage (kV) minimum clearance distance m				
	<33	66	132	275	400
Line conductor to any point not over a road	5.2	6.0	6.7	7.0	7.6
Line conductor to road	5.8	6.0	6.7	7.4	8.1
Line conductor to any object on which a person cannot stand	0.8	1.0	1.4	2.4	3.1

Table 3 Information on line clearance distances extracted from ENA TS-43-8

GS 6 provides specific instructions on avoidance of danger from overhead powerlines. It states "The safety zone should extend 6 m horizontally from the nearest wire on either side of the overhead line. You may need to increase this width on the advice of the line owner or to allow for the possibility of a jib or other moving part encroaching into the safety zone. It may be possible to reduce the width of the safety zone, but you will need to make sure that there is no possibility of encroachment into the safe clearance distances in your risk assessment"

Additional guidance is given in GS 6 on signage, use of illuminated signs for poor weather conditions, maintenance of barriers and access roads and use of cranes in the vicinity of powerlines.

Figure 7 Typical construction arrangement at overhead powerline crossing taken from GS 6

When a new pipeline is strung out above ground in close proximity to an overhead power line then capacitive coupling can create voltages in excess of 100V rms on individual pipes or welded strings of pipe dependent upon the situation. This could provide a touch potential risk to workers and also affect welding operations.

The risk of electrical shock would be limited as the available current should be low, since the a.c voltage would be created by capacitive coupling. However, contact with a pipeline could result in an unexpected involuntary action that could result in an injury or fall. The latter risk needs to be considered and where necessary suitable mitigation methods employed.

It would be important that pipelines strung out near overhead power lines are effectively grounded by the use of at least two grounding electrodes at each end of an individual strung out pipeline section. Grounding/earth connections should be installed first and then be connected to the pipeline. They must be removed in the reverse order i.e. connections to the ground MUST be removed last.

Suitable test equipment should be employed to confirm that a strung-out pipeline section does not pose an electrical shock risk prior to commencing work. The Australian Pipeline Industry Electrical Hazard Guidelines advise "Very often, if the mobile plant is metal tracked, the operator will survive this contact so long as the operator stays on the machine.

If it is essential to leave the machine the operator must jump clear from the machine to avoid touch potential voltages on the machine, then hop away (with feet together) to avoid step potentials on the ground near the machine.

Depending on the voltage being carried by the system, tyres of wheeled equipment coming into contact can be blown out and/or catch on fire and persons some distance away from the incident can be injured by the light and heat energy released by the electrical discharge (known as the arc flash).

The power system may register the contact as a line fault and trip the supply. The system may also attempt and reset the trip, within seconds. A second trip may occur and the system at fault may remain isolated. Phase to earth fault may not operate the protection system and this does not cover a circuit protected by fuses HV or LV.

The operator must not make contact with the machine at the same time as ground contact is made. It is important in the case of work near overhead and buried powerline cables to ensure that emergency procedures are in place and include details of location of the nearest hospital and pipeline and power system operator emergency contact numbers.

4.12 Pipeline to pylon separation

It is important to maximise the separation distance between pipelines and power line pylons.

Canadian Standard CSA –C22.3 recommends a minimum pylon to power line spacing of 10m. However, the latter standard does state that line-to-ground faults can cause damage to pipeline coatings or pipelines even with clearances in excess of 10m

BS EN 50443 does give guidance on the separation between pipelines and power lines however, the guidance is not clear. *Section 5.3.2 of BS EN 50443 states "In rural areas, for soil resistivity below 3 000 Ω m, an interference distance of 3 000 m between the interfering system and the metallic pipeline system should be considered. In case of soil resistivity value greater than 3 000 Ω m, the interference distance value, in metres, should be equal to the soil resistivity value in Ω m.*

In urban areas, for soil resistivity below 3 000 Ω m, BS EN 50443 advises that the interference distance should not be less than 300 m. For soil resistivity greater than 3 000 Ω m the interference distance, in metres, should be equal to the soil resistivity value, in Ω m, divided by 10.

The guidance given above relates to determination of long term induced voltages and not short-term voltages created during fault conditions.

The actual separation distance between a pipeline and pylon is determined by the line voltage, fault current and local soil resistivity and the separation distance should ensure that the touch potential induced on a pipeline under fault conditions at a power system earth is below safe limits.

AS/NZS 4853 gives an indication as to the effective separation distance between an overhead power line and pipeline for different fault current conditions has on touch potential risk. The information is given in Table 4

Fault current A	Separation required (m) for two different soil resistivity values	
	100 Ω.m	500 Ω.m
1000	60	310
3000	190	940
6000	380	1900
10000	635	>3500

Table 4 Separation distance between pipeline and power line pylon for touch potential limit of 220V on pipeline from AS/NZS 4853

It can be seen that separation distance between a pipeline and power line does need to be maximized to ensure that the touch potential risk is controlled. Table 4 gives the distance to the 220V voltage contour extracted from AS/NZS the separation distance for the 650V voltage contour commonly employed in the UK to assess safe voltage limits will be a lot lower.

Table 4 serves to indicate that the pipeline power line separation distance needs to be considerably greater than 10m to mitigate a touch potential risk during fault conditions on HV pylons. It should also be noted that coated pipelines are not perfect insulators. The pipeline will act as a good conductor and the voltage field will be distorted during a fault condition and thus the voltage seen on the pipeline where it crosses a voltage contour line will spread some distance along the pipeline from the fault location.

It is important that all pipelines are assessed in terms of short-term voltage risk and that the pylons in close proximity to the pipeline are identified and the maximum touch potential risk that a pipeline will experience is identified.

The voltage contour diagram for a pylon tower at a fault current of 10kA in soil of resistivity 100 Ohm m is given in Figure 8.

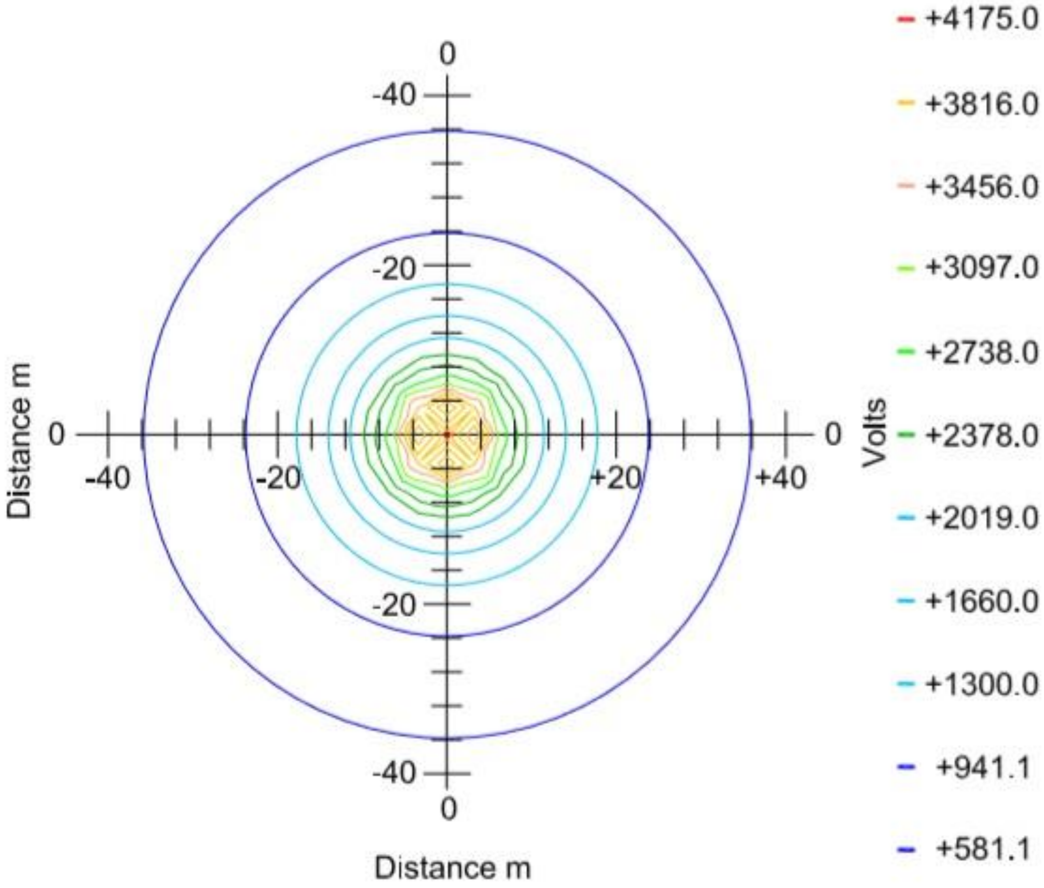


Figure 8 Voltage contour diagram for fault current of 10 kA with 50m of a pylon in soil of resistivity 100-ohm m [33]

Since the voltage contour values vary depending upon soil resistivity, pylon resistance and fault current it is not possible to specify a safe separation distance between pylon or substation and pipelines to ensure a safe touch potential during fault conditions. To ascertain the safe distance for a given situation mathematical models using specialist software need to be conducted,

Figure 8 shows that transfer voltage on a pipeline would be about 580V at a distance of 40m from the pylon but within 10m of the pylon the voltage would about 2,300V. Thus, in this instance at a distance of 35m separation between pipeline and pylon footing a safe touch potential value less than 650V will be experienced. If the soil resistivity in which a pylon is installed was higher for a similar fault current, then the separation distance would need to be at considerably greater.

4.13 Repairs to pipelines or discontinuities in pipelines

If a pipeline system requires maintenance or remedial work requiring sections of pipe to be cut out, then consideration should be given to the fact that there may be long line a.c. and d.c. currents flowing in the pipeline. The current could be induced a.c. from overhead or buried power lines and would also include d.c. current from a pipeline CP system or as a result of d.c. stray current interference.

If such a situation is considered to exist, then a bond cable should be securely connected to the pipeline each side of the proposed discontinuity. The bond cable should have a minimum conductor size of at least 35mm^2. The bond cable should be flexible and securely connected to the pipeline outside any hazardous area. There should be sufficient slack cable allowed to account for possible movement of the pipeline following any cutting operation, which could cause detachment of the bond cable (see Figure 9).

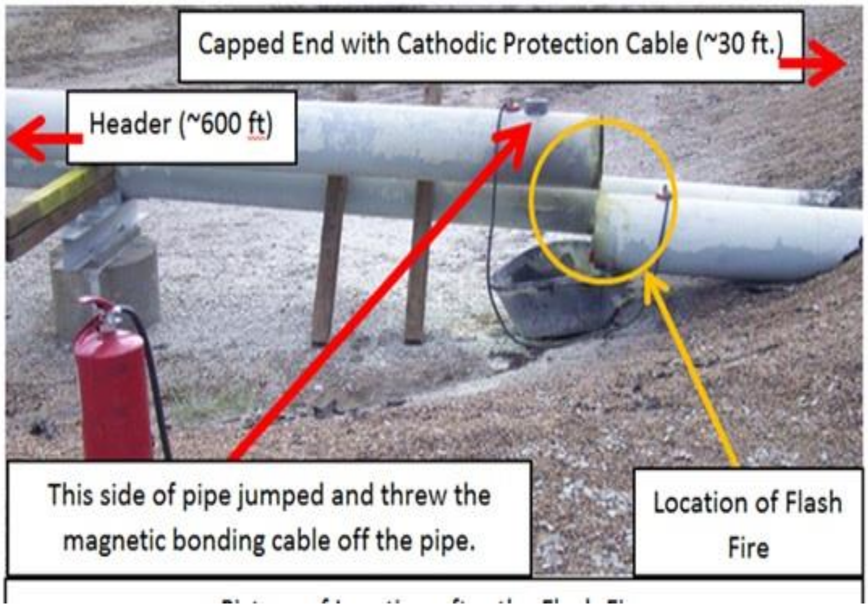


Figure 9 Picture of situation where bond disconnected on cutting on cutting pipeline resulting in incendive ignition of flammable material.

A solid permanent bond was then used. Where bonds are installed, they should be solid bonds not capable of being easily removed and have sufficient flexibility.

Where a hazardous area will be created by any stoppling or cutting operation, no current carrying cable to pipe connection should be made in a hazardous area.

The current flowing in any bond cable should be measured with a clamp meter to ascertain the current magnitude as the spark energy available if any cable is disconnected is related to the square of the current. The a.c current flowing in a pipeline may approach a few tens of Amps and would create a spark risk on disconnection.

4.14 Lightning

4.14.1 General

There is, as far as UKOPA is aware, no published UK HSE guidance on precautions to take in the event of lightning. However, it is believed the HSE do have plans to publish guidance in the future. ROSPA [34] does give guidance for leisure interests and they advise that if thunder is heard work should cease and if operatives can they should take shelter in an all metal cabin. The guidance provided by ROSPA is summarised in italics in this section. The OHSA [35] in the USA also provide guidance. BS EN 62305-2: [36] provides advice on lightning risk management the latter standard primarily concentrates on risk of damage to structures.

If in a field in the open personnel should stay as low as possible and when close to powerlines should not shelter at a pylon but at the midpoint between pylons. ROSPA advise that;

Lightning strikes the ground in Britain about 300,000 times a year. For the climber, fisher, walker, golfer, and other exposed persons, this is a risk that must be considered. Although there is no absolute protection from lightning, measures can be taken to reduce the risk of getting struck and the injury severity. This fact sheet provides information about lightning, statistics, and precautions, both for the individual, and advice for strategies that can be taken by leisure operators and event organisers.

30-60 people are struck by lightning each year in Britain, and on average, (5-10%) of these strikes are fatal. UK mortality statistics show that in 2005 there were two fatalities caused by lightning strikes. Those most at risk are those who are outdoors often, exposed in vulnerable, unsheltered locations. Research has also shown that proximity to water increases the risk of being struck by lightning. The time that is most dangerous is when there is underestimation of the likelihood of being hit, for example before the storm or when you think it is over. There are three different ways of being struck by lightning:

1. *Direct strike: the lightning hits you and goes to earth through you.*
2. *Side Flash: the lightning hits another object and jumps sideways to hit you.*
3. *Ground strike: the lightning strikes the ground then travels through it hitting you on the way*.

To check if a storm is coming or going from where you are standing apply the flash to bang principle, counting as soon as the lightening flash is seen until the thunder is heard. 'Flash to bang' is based on the following facts:

1. *Sound travels at 330 meters per second or at 1 km in 3 seconds (approximately 1 mile every 5 seconds).*
2. *Light travels at 300,000 km per second.*
3. *Lightning will always be seen before thunder*.

To calculate the distance between yourself and the storm divide the number of seconds by 3 to find the distance in kilometres. If the distance between the thunder and lightning increases over a couple of strikes, the storm is moving away. If it decreases, it is coming closer.

4.14.2 30/30 rule

Research shows that people struck by lightning are predominantly hit before and after the peak of the storm. This means that you should be thinking about the proximity of the lightning, not the occurrence of rain. The 30/30 rule provides a good way of ensuring one is sheltering during the riskiest parts of the storm. It proposes that if the flash to bang is 30 seconds in length or less you should seek shelter. Staying inside this shelter is advised until 30 minutes past the last clap of thunder. This ensures that any distant strikes at the beginning of the storm (lightning can travel up to 10 miles), or trailing storm clouds at the back of the storm do not take anyone by surprise.

4.14.3 Seeking shelter

- Ideally, seek shelter inside a large building or a motor vehicle keeping away from, and getting out of wide, open spaces and exposed hilltops.
- If personnel are exposed to the elements with nowhere to shelter, make as small a target as possible by crouching down with feet together, hands on knees and the head tucked in. This technique keeps as much of a person off the ground as possible.
- The inside of a car is a safe place to be in a storm, lightning will spread over the metal of the vehicle before earthing to the ground through the tyres.
- Do not shelter beneath tall or isolated trees, it has been estimated that one in four people struck by lightning are sheltering under trees.
- If on water, get to the shore and off wide, open beaches as quickly as possible as water will transmit strikes from further away. Studies have shown that proximity to water is a common factor in lightning strikes.

4.14.4 Individual safety

- Before work commences, check the weather forecast. If there are storms are predicted think about doing something less exposed or being somewhere that provides appropriate shelter nearby.
- Be aware of objects that can conduct or attract lightning.
- Seek shelter quickly if your hair begins to stand on end and nearby appliances begin buzzing - it may mean lightning is about to strike.
- Inside a building lightning can be conducted through television aerials, piping or other wires. Except in cases of emergency, don't use a telephone (land-line or mobile) until the storm is over.

4.14.5 Employers requirements

Workplaces have a duty to ensure the health, safety and welfare of their staff under the Health and Safety at Work Act 1974 [37] Section 2(1). If staff are working outdoors in exposed areas, this must be reflected in the risk assessment.

Projects should be thoroughly risk assessed, and if there is a risk of being struck by lightning this must be looked at and control measures put in place with a lightning safety plan.

Think about the following recommendations:

- In case of work on pipelines, monitor the local weather from the day before work activities commence.
- Have an efficient method of warning people at risk, and evacuation if necessary.
- Define and list safe structures and locations. Safe structures can include a large/substantial building with plumbing and wiring that will conduct lightning to the ground such as fully enclosed metal vehicles including buses.

- Determine criteria for suspension and resumption of activity – for example, use the 30/30 rule.

- Ensure the dissemination of information, and that staff must be aware of potential dangers and how to minimise the risk of injury

- Situations where lone working is involved, and personnel may be involved in electrical hazard risks should be assessed and operatives required to identify work areas and sign in at the start and end of each day.

4.14.6 In case of emergency

If someone is hit by lightning, call emergency services – they will need help as soon as possible. If you know first aid, apply it – you will not receive an electric shock. A lightning strike is not usually instantly fatal, victims' hearts and/or breathing may stop however, so quick application of CPR will likely save their life.

If someone is hit by lightning, call the emergency services – they will need help as soon as possible. If personnel attending an incident are suitably qualified first aid should be applied – in the event of a lightning strike personnel assisting the injured person will not receive an electric shock unlike in the case of a person experiencing an electrical shock from a cable. A lightning strike is not usually instantly fatal, victims' hearts and/or breathing may stop however, so quick application of CPR will likely save their life.

4.14.7 Prevention of injury and risk assessment

BS EN 62305-3 [38] provides guidance on avoidance from injury from touch potentials caused by lightning. In certain conditions, the vicinity of the down-conductors of a lightning protection system, may be hazardous to life even if the lightning protection system has been designed and constructed according to the BS EN 62305-3 requirements.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

a) Under normal operation conditions there are no persons within 3 m from the down conductors;

b) A system of at least 10 down-conductors complying with section 5.3.5 of BS EN 62305-5 are employed;

c) The contact resistance of the surface layer of the soil, within 3 m of the down-conductor, is not less than 100 kΩ.

NOTE A layer of insulating material, e.g. asphalt, of 5 cm thickness (or a layer of gravel 15 cm thick) generally reduces the hazard to a tolerable level. If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to touch voltages as follows: – insulation of the exposed down-conductor is provided giving a 100 kV, 1,2/50 μs impulse withstand voltage, e.g. at least 3 mm cross-linked polyethylene; – physical restrictions and/or warning notices to minimize the probability of down-conductors being touched. Protection measures shall conform to the relevant standards (see ISO 3864-1 [39]*).*

Similar measures are recommended in relation to mitigation of step potential hazards protection measures shall be adopted against injury to living beings due to step voltages as follows: - equipotentialization by means of a meshed earth-termination system; - physical restrictions and/or warning notices to minimize the probability of access to the dangerous area, within 3 m of the down-conductor

Thus, in relation to AGI fences pipeline standards often specify that earthed components are not installed within 3m of fences or other independently earthed structures to mitigate touch potentials from lightning strikes. If warning signs are installed on fences to warn about the hazards from electrical contact, they should also advise that there may still be a touch or step potential hazard within 3m of the fence or similar structure.

4.14.8 Damage to pipelines from lightning

There have been incidents where lightning has struck a buried pipeline. These events are relatively rare but do occur. It is often difficult to determine whether any damage was caused by lightning or a phase to earth fault on an overhead power line.

Evidence of a lightning strike damage will be recorded by either damage to cables in CP test facilities or from damage to CP T/R units connected to pipelines. The fault current magnitude in a lightning strike can be up to 100kA but whilst the magnitude of the lightning current may be high the duration of the current flow is in the range of microseconds to a few milli-seconds. In certain circumstances through wall metal loss can be experienced.

Figure 10 Picture of lightning damage to a buried pipeline. The damaged resulted in through wall penetration on a high-pressure gas pipeline.

In some areas of UK there is a higher risk of lightning than in others. Thus, the risk for personnel working on pipelines from lightning does vary. Figure 11 shows the lightning density map for the UK given in BS EN 62305-2, which show that there is a higher lightning risk in the South of England than Scotland.

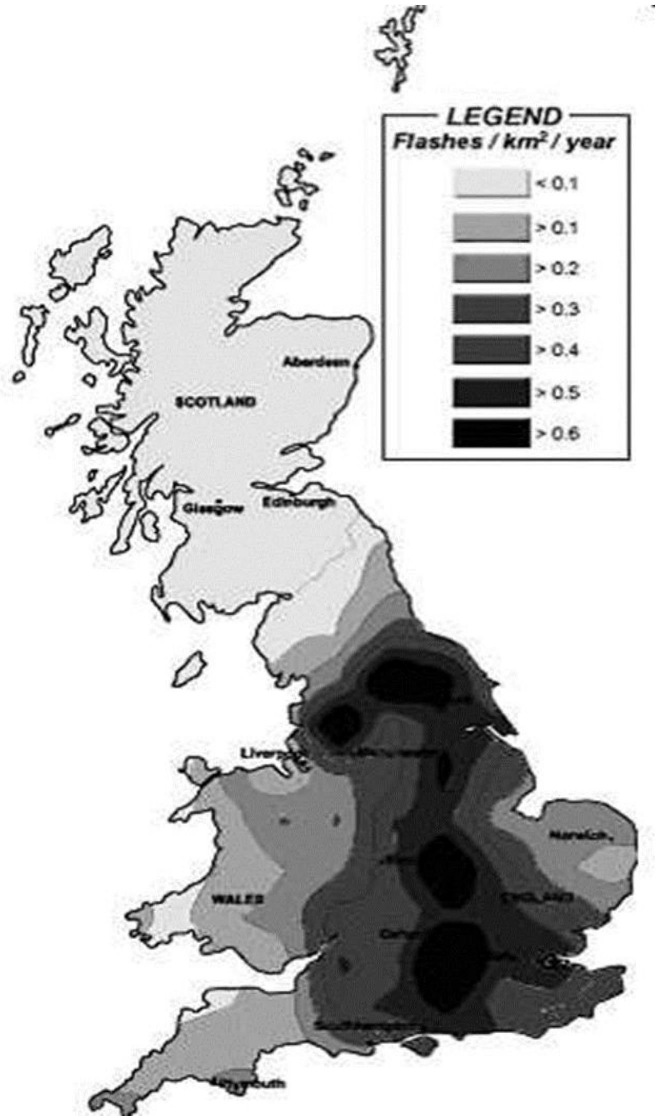


Figure 11 Lightning density map for UK extracted from BS EN 62305-2.

4.15 Quantified risk assessments

If there any locations on a pipeline where it has been identified that there is high risk in terms of electrical safety, and the touch potential limits exceed safe limits, then prior to undertaking any work on pipelines in these locations then a quantified risk assessment (QRA) should be conducted by a competent body. The QRA should consider the nature of the activities on the pipeline to be conducted, the number of personnel involved in the activities, and time spent in possible contact with the pipeline.

Exposing a pipeline for inspection or repair can significantly increase the period of time personnel could be exposed to contact with a pipeline and thus increase risk of being exposed to an electrical shock in certain situations. The assessment should also consider the nature of the touch potential current path e.g. whether foot to hand, hand to hand or hand to knee.

The measures that could be employed to mitigate risk in any QRA should identified e.g. PPE, avoidance of different earthed structures, temporary earthing, trench construction etc.

The nature of the work being undertaken may be inspection of the pipeline following an ILI to identify and measure features, coating repair operations, clamp shell repairs, diversions and hot tap and stopple operations, nitrogen filling of sleeves, CIPS etc.

AS/NZS 4853 provides examples of quantitative risk assessments for such situations. Any risk assessment should be based upon the requirements of the Management of Health and Safety Regulations 1999 [40]. The risk assessment should include an assessment of the most exposed individual, identification of a range of risk mitigation, quantification of the level of risk reduction provided by these risk mitigation measures and a cost-benefit analysis to demonstrate that the chosen measures reduce risk levels to as low as reasonably practicable.

Any risk mitigation measures required by an ALARP assessment should be installed before any new electrical power system is commissioned.

5. INDUCED A.C. VOLTAGE LEVELS AND ASSESSMENT OF RISK

5.1 Mathematical modelling

Mathematical modelling using specialist proprietary software is required to determine the long term and short-term a.c. interference levels on pipelines. The short-term voltages will result from a fault on overhead power line pylons, at a HV substation or from buried cable joint bays, whilst the long-term voltages will result from parallelism between pipelines and overhead or buried pipelines.

It is recommended that companies which specialize in assessment of a.c. interference from cable systems and employ suitability qualified electrical engineers undertake the mathematical modelling work. Only proprietary software with a proven track record for use in modelling induced a.c. interference levels should be used for mathematical modelling studies on pipelines using finite element modelling.

In the case of short-term interference, it is recommended that selected high-risk locations e.g. locations on pipelines in close proximity to a pylon or substation particularly in high soil resistivity locations should be identified and modelled to determine the maximum touch potential that will be experienced on the pipeline during fault conditions. If touch potential limits exceed the required limits, then additional models at alternative locations on a pipeline may need to be undertaken. The effect of ground potential rise from multiple pylons along a pipeline section may need to be considered

Pipeline CP TR units may also act as earth locations along a pipeline route where fault currents may discharge to earth through the T/R unit and CP groundbed. Modelling should be considered to assess the short term GPR within the vicinity of any CP groundbeds as part of any a.c. interference study.

Caution should be exercised as the mathematical models created to determine the levels of long-term interference may not be accurate as a number of assumptions are made when creating the model.

Experience has shown that whilst mathematical models can be useful, they may not always produce an a.c interference mitigation system design that will be fully effective and changes to the mitigation arrangement on a pipeline may be required in the future following commissioning of any a.c. mitigation system and subsequent monitoring data.

Operators should validate mathematical models by undertaking appropriate a.c. monitoring on a pipeline system following installation of an a.c. mitigation system or operation of any new cable system. This will assist in validation of any model and confirmation of the model accuracy. To undertake system validation exercises precise information on the loads on the individual power line circuits at the time any data logging is performed would need to be established.

Mathematical modelling requires accurate information on the pipeline and power line route, details of the power system including rated and maximum loads, power cable pylon construction and details of the screen wire

The information would be required by companies engaged to determine the short term and long term a.c. interference levels on pipelines using proprietary software packages is given in Appendices C, D and E of UKOPA/GPG/027. The typical questionnaires given in UKOPA/GPG/027. The information provided in the power line operator questionnaires contains details of information required to model not just long term but also short-term interference levels.

The company undertaking the modelling work should advise details of the information that will be required off power line operators to conduct the modelling studies e.g. fault current at substations and pylons, fault duration, shield wire construction, information of supply feeds to substations, power cable height above ground, power cable construction, operating voltage and circuit loading.

5.2 Induced voltage levels buried cables on pipelines

The a.c. interference levels on buried pipelines from buried cables should be assessed based upon the guidance given in CIGRE TB 95. It should be noted that the long term a.c. interference levels on pipelines from buried cables are lower than for overhead power lines with a similar separation distance between the pipeline and power line and would not generally create a significant long-term touch potential risk. The higher the power cable operating voltage is the higher the levels of induced a.c.

The a.c. voltages present on an existing pipeline should also be taken into consideration when assessing the risk of interference from new buried cable systems since, whilst the existing a.c. voltages may be within limits to ensure no a.c. corrosion or touch potential risk on a pipeline prior to installation of any cable system, even a small induced voltage from the new buried cable system could add to the a.c. voltages already present on a pipeline and create a risk.

The existing a.c. voltages present on pipelines may be from existing power overhead power lines in the area and from the a.c. ripple voltage on the d.c. output from CP T/R units.

The addition of a.c. voltages is not a simple numerical addition and any voltage additions may need to be treated as vector values.

In the case of new HVAC buried cables routed alongside pipelines then modelling should be carried out to confirm the levels of long term induced voltage as there may be situations that can create elevated voltage levels e.g. each change in phase transposition on the cable system or the presence of acute crossing angles. If cable joint bays are located close to a pipeline, then there may be high touch potentials created during fault conditions and the touch potential risk on a pipeline during fault conditions should be ascertained.

On factor that should also be considered is that buried HV power cables will provide an increased load to electrical substations and as a result additional current loading may also be provided to overhead power lines in area. The additional power load on any overhead power lines created by the new buried cable system would also need to be considered as part of any model.

5.3 Induced voltages overhead cable systems

The long-term a.c. interference risk on buried pipelines from overhead power lines can be calculated based upon the guidance on calculation methods given in CIGRE TB 95 and GIGRE TB 290 [41] AS/NZS 4853 and ISO 21857 also provide examples of typical calculations and calculation methodology.

The models can take time to run and should be conducted by specialists experienced in producing a long-term interference model using the software that will be employed.

In the case of both new and existing pipeline system the models should evaluate the long term and short term a.c. interference risk along the entire length of the pipeline system.

The models should be produced for both the unmitigated and mitigated situations. The pipeline operator should agree with the company undertaking the modelling the loads on the power line system that should be considered for the model. These scenarios would include the normal power line load, the maximum load anticipated on the power line and the rated load i.e. the load that the power line system can theoretically take.

The normal load is the load that would normally be present on a cable system. The maximum load is the load that a power cable system could be expected to carry with the existing power generation systems feeding. The rated load is the load that a power cable can theoretically carry.

The loads in the power cable circuits may not be equally balanced. During unbalanced load situations the levels of current flowing on different cable circuits can vary. If such a situation exists, then the levels of induced pipeline voltage will also vary. The selection of load scenarios to model should be agreed with the modelling company.

If one circuit of a two-circuit power line is operating at a lower load than the other then this can create higher levels of induced voltage on a pipeline, than in the balanced load scenario.

If there is just one circuit of a two-circuit power cable operating, then that will generally create a higher long-term voltage than with both power circuits operating. Such a situation may exist when there is maintenance being undertaken on one circuit for example and would be for a short duration typically measured in terms of weeks.

5.4 Rail traction system interference

If pipelines cross a.c. traction systems at right angles and do not run in parallel with the traction system for any appreciable distance, then the levels of interference from a 25kV traction system should be low.

Where a pipeline crosses a rail line, the crossing should be at right angles and the pipeline should be routed so that it is equidistant between rail line pylons. This will limit the ground potential rise on the pipeline during fault conditions on the traction system. Fault currents on rail traction systems vary with distance from the substation, with typical values in the region to 1 to 12 kA. The fault current at specific location should be established.

The a.c. interference risk in relation to pipelines in close proximity to railway systems occurs where the pipeline is routed in a parallel with the traction circuits and can collect traction return currents by resistive coupling and also inductive/capacitive coupling from the live traction cables.

BS EN 50443 advises that capacitive coupling from a railway system has to be considered in case of proximity lower than: -

- 10 m in case of 15 kV, 16,7 Hz systems;
- 50 m in case of 25 kV, 50 Hz systems.

BS EN 50443 advises that conductive or resistive coupling from an a.c. electric traction systems shall be considered in case of crossing or proximity lower than 5m from the nearest rail or masts or metallic components connected to the rails.

However, practical guidance would be that separation distance of at least 20m should be considered between rail line and traction line earths.

Modelling of the effects of a.c. interference from a.c. traction systems should be undertaken by specialists experienced in this field. The nature of the rail electrification system would need to be established and information provided on the location of any a.c. booster stations, train frequencies on the rail line and operating currents for different scenarios. The relative positions of feed and return conductors including earth wires should be confirmed, the number of substations and distance the traction circuit runs parallel with a pipeline and separation distance between the two.

The maximum and normal loads on the rail system and fault current at substations and on pylons close to pipeline should be confirmed and the rail operator should provide information on the number of track circuits and power lines operating at 25 kV and their physical location. The analysis of a.c. traction system interference is made complex due to the fact that the traction current has a variable location due to the movement of the trains and variable magnitude of current load associated with variation in acceleration and breaking. The current loads can change over a relatively short period of time.

The overhead aerial earth wire also has a shielding effect in reducing the levels of interference. No pipeline a.c. corrosion mitigation system earth should be installed underneath a rail line since during fault conditions such as an overhead powerline fault or lightning strike on a pipeline the fault current may discharge through the pipeline earth and the resultant ground potential risk may affect rail signalling systems.

All apparatus, cabling and earth systems associated with a pipeline system installed under railway lines or connected to rail lines must be approved by the rail authority.

A HAZOP and HAZCON should be carried out between the pipeline operator and railway operator for new construction activities in the vicinity of rail crossings to ensure safe operation of the pipeline and railway.

In terms of the safety risk from interference from a.c. traction system the short term a.c. voltages should be limited provided there is adequate separation between the 25kV pylons for the rail traction system and a buried pipeline. The ground potential rise on a pipeline from a fault on the traction system tower should be assessed to ensure it is within safe limits.

5.5 Soil resistivity

A soil resistivity survey should be carried out as part of any mathematical modelling studies. The soil resistivity data at depth will be required and soil resistivity data at varying pin spacings up to 60m may be required to complete mathematical models on complex systems.

Low soil resistivities less than 25 Ohm m create a high risk of a.c. corrosion but, high soil resistivities e.g. > 100 Ohm m will result in a higher GPR at a pylon. Thus, in terms of electrical hazard risk and touch potentials on pipelines, where a high soil resistivity is present this will mean that the pipeline to pylon separation distance will need to increase to bring the touch potentials on a pipeline for a given fault current within safe limits.

6. ASSESSMENT OF A.C. INTERFERENCE RISKS

6.1 Introduction

The determination of the safety related a.c. interference risks on a new pipeline and design of any mitigation measures would be undertaken in conjunction with the design of the pipeline CP system. Thus, the requirements of any pipeline operators' specific standards plus those of BS EN 50443 should be followed in relation to assessment of a.c interference risk.

In relation to existing pipelines operators should ascertain where there may be electrical safety concerns and determine locations where the short-term electrical touch potential risk on the pipeline system may exceed 650V. The short-term voltage levels on new pipelines should comply with the guidance given in this TBN, ENA TS 41-24 and BS EN 50122-1.

As stated, in section 4.1 there may be locations on existing pipelines where the touch potential experienced during fault conditions exceeds the safe limits detailed in either BS EN 50122-1 or BS EN 50443. These locations should be identified, and operators should ensure safe working procedures and risk assessments are in place to monitor and reduce the risk.

Operators should also identify pipelines where the long-term a.c voltage limits exceed 15V rms.

6.2 Pipeline route selection

Consideration of the risks of a.c. interference should form an integral part of the route selection process for any new pipeline system. Wherever possible, pipelines should be routed as far as possible from overhead power lines. Thus, pipeline routes should be selected to avoid or minimize a.c. interference and an assessment of the a.c. interference risk should be included in the route selection process.

Where parallel runs of pipelines and power lines are present, voltage peaks may occur where there are discontinuities such as insulating joints, a junction of two or more pipelines, and at abrupt changes in power line to pipeline configuration or cable transposition locations.

Pipelines should not cross power lines at acute angles; ideally, they should cross at right angles.

Adequate separation should be achieved between pipelines and power lines and the separation distance should be at least 0.6m and for HV power cables greater than 33kV a greater separation distance should be considered. Insulating mating to prevent contact between power lines and pipelines should be considered and installed midway between the pipeline and power line (see Section 4.9 for additional guidance).

Cable warning tape should also be installed above any buried power cables at the pipeline crossing point and the cable location identified on as built drawings.

Electrical substations within the vicinity of pipelines should be located and sufficient distance away from a pipeline so as not to cause a touch potential in excess of safe limits during a fault situation or ground potential rise event.

6.3 Pipeline design code requirements

The pipeline design code requirements in relation to a.c. interference should be identified and complied with. In the UK natural gas pipelines will generally be designed to IGEM/TD/1 [42] and oil or petroleum product pipelines to PD-8010-1 [43]

PD-8010-1 states "If *personnel safety is at risk from a.c. voltages on the pipeline or if an a.c. corrosion risk exists, measures should be taken to mitigate the risk. These should include:*

- *earthing laid parallel and connected to the pipe.*
- *earthing mats at valves.*
- *connection of polarization cells or their solid-state equivalent across electrical isolating devices. to connect the pipeline to earth and to protect the electrical isolating device.*
- *dead front test posts to prevent third-party contact.*

NOTE 1: One of the methods of monitoring the a.c. corrosion risk is by measuring the a.c. current flowing at a buried coupon installed at the location where the a.c. interference is believed to be at its greatest. These coupons normally comprise a coated metal plate with an exposed bare steel area of

1cm^2. The coupon is normally connected to the pipe via a shunt that enables both the a.c. current flow and the d.c. current flow to be measured.

NOTE 2: Mitigation measures may be installed retrospectively, but this carries a risk of a.c. corrosion occurring before installation is complete. The installation of further mitigation measures might be necessary if the power line load increases.

PD 8010-1 advises that the need for a.c. mitigation should be identified at the design stage and this may be achieved by computer-modelling of the power line/pipeline interaction.

The standard most widely adopted for the design of high-pressure gas pipelines in the UK namely IGEM/TD/1 Edition 5 only provides guidance in relation to a.c. corrosion. It does not provide or specify any specific guidance on the electrical safety hazards. It should be noted that gas pipeline operators have developed their own standards that provide advice on electrical safety hazards and where operators have their own company specific standards these should be consulted, and the guidance contained therein followed.

Pipeline design standards requirements in relation to a.c. interference should be assessed, but it should be noted that they may not always specify the latest guidance in relation to a.c. interference risks.

It is considered to be beneficial for operators to seek expert advice on a.c. interference issues and to follow the guidance in this TBN in addition to the information included in the relevant pipeline design code and other applicable BS/ EN standards.

6.4 Assessment

Operators should carry out an assessment of the level of risk of a.c. interference on all pipeline systems. If a.c. interference has been identified as a risk, then appropriate measures should be implemented. It should be stated that not all pipelines may be susceptible to a.c. interference. The assessment process should be documented.

Details on the factors to consider in relation to existing pipelines in terms of assessment of risk are given in section 7.0 of this TBN.

The measures to monitor and mitigate the risk should include the guidance given in this TBN and, BS EN 50443 plus any specific pipeline operator codes and standards.

It should be noted that the level of risk to pipeline systems should be reviewed on a periodic basis as situations may change over time. Thus, the process of assessment should be ongoing over the life of a pipeline system as new power lines or electrical substations may be installed in the vicinity of pipelines or the loads on existing power lines increased. If such a situation occurs, then the level of induced voltage on a pipeline may change.

It should be stated that not all pipelines or sections of a pipeline may be susceptible to a.c. interference.

Pipeline systems should be evaluated on a case by case basis and any assessment should be prioritised with pipelines considered to have the highest level of risk being assessed first.

Power line operators do not routinely advise pipeline operators if there is going to be a significant change in the power load of a given power line circuit. Thus, pipeline operators should monitor the levels of a.c. interference on pipelines even if they are not considered to be at risk and monitor planning applications. This will assist in identifying if there are any new developments planned within 1,000m of a pipeline that may result in an enhanced a.c. interference risk e.g. new power stations, wind farms, solar farms and new overhead and power cable routes

If pipeline diversions are required, the risk of increased levels of a.c. interference on the existing pipeline as a result of any change in the pipeline route should be considered. In addition, where a diversion employs a higher performance coating system than that employed on the existing coating system the enhanced touch potential and a.c. corrosion risk on the higher dielectric strength coated pipe sections should be considered.

Measurement of the a.c. voltage on a pipeline over a period of time will give an assessment of the long term but not short-term risks

CIGRE TB 95 gives guidance on the relationship between zone of influence and power line pipeline separation. Operators should carry out an assessment of the risk of a.c interference on all metallic pipeline systems that they are responsible for. If a.c. interference is then identified as a risk, appropriate measures should be implemented to monitor and mitigate the risk.

Pipeline operators should assess both the a.c. corrosion risk and the electrical safety risk to personnel. It should be stated that not all pipelines or sections of a pipeline may be susceptible to a.c. interference.

The a.c. interference risk on all existing pipelines should be assessed in accordance with the pipeline design code requirements. All overhead power lines or a.c. substations within 1000m of a pipeline system operating at voltages of 66 kV or above should be considered.

6.5 Competency and certification

It is recommended that any a.c interference monitoring, installation, and data assessment should be carried out by personnel having the required levels of competency as defined in BS EN ISO 15257 [44].

Any a.c monitoring and mitigation system designs should be carried out by a Level 4 certified Senior Cathodic Protection Engineer as defined in BS EN ISO 15257.

Pipeline operators should however confirm that personnel employed in design and monitoring process even if BS EN ISO 15257 certified have the required levels of experience and competency in assessment of a.c interference risks on pipelines.

In relation to the assessment of electrical hazards on pipelines it is considered that only suitably qualified and experienced Electrical Engineers would have the competency to assess electrical safety hazards on pipelines. CP personnel having the competency levels defined in BS EN ISO 15257 do not generally have the required levels of electrical competency or awareness to identify electrical safety risks

Certification of personnel to BS EN ISO 15257 would not provide the required level of safety awareness in relation to the electrical safety risks associated with work on pipelines or AGIs and operators should provide relevant training.

6.6 International guidance electrical hazards

The safety aspects of a.c. interference on pipelines from a.c. power lines and traction systems on pipelines are detailed in other international standards or publications e.g. AS/NZS 4853:2012. The Australian Pipeline Industry – "Guidelines for Electrical Hazards" Version 2 15/1/14. CAN/CSA-C22.3 No. 6-M91 and NACE SP0177.

The latter standards and publications do provide additional guidance to that contained in this TBN and should be consulted for further information.

6.7 Energy Institute Electrical Safety code requirements

The safety aspects of a.c. interference on pipelines are also defined in the Energy Institute Model Code of Safe Practice Part 1 [45].

The Energy Institute Electrical Safety Code provides guidance on electrical safety issues on pipelines. It permits a maximum pipe to soil potential for electrical safety of 25V rms, which although slightly higher than the limit advised in this TBN is in line with the information contained within this document.

Guidance is also provided in the EI document on electrostatic hazards, grounding of above ground pipelines and lightning protection for pipelines. There is no guidance provided on a.c. corrosion risks in the EI Electrical Safety Code.

7. ELECTRICAL HAZARDS IN SPECIFIC SITUATIONS

7.1 Introduction

This section of the TBN provides information on specific situations where an electrical hazard to pipelines and/ or pipeline personnel may exist.

7.2 Monitoring facilities

On pipelines where a.c. interference has been identified, if the a.c voltage levels are expected to approach unsafe levels in terms of touch potential and the general public may be exposed to an enhanced risk then dead front CP posts, which require access to pipe connections with a key should be considered.

A typical example of a dead front test facility would be a Lighting Control Pillar, which requires a key to facilitate access to test cable connections. Where dead front test facilities are utilised access to pipe connections can be controlled and this will mitigate any touch potential risk. Suitable warning signs constructed in accordance with ISO 3864 should also be provided preferably with red lettering to advise of an electrical hazard risk.

CAN/CSA-C22.3 No. 6-M91 provides information on the use of zinc earth mats connect to the pipeline at CP tests posts to mitigate touch potential risks. The use of earth mats at CP test facilities to mitigate touch potential risks is not standard practice on pipelines in the UK.

7.3 Pipeline AGIs close to radio frequency transmitter stations

There is a risk of high frequency a.c. interference from microwave transmission towers installed close to AGI's on above ground pipeline systems and portable equipment. The induced voltages can result in an incendive ignition risk of flammable atmospheres under certain conditions. It is important that pipeline operators are aware of this risk when granting permission for the construction of microwave transmission towers in close proximity to AGI's or where there are transmission towers installed close to existing AGI's.

Any assessment should be carried out by an independent body that specialises in the assessment of high frequency interference in such situations. The assessment of the risk should be carried out in accordance with PD/CLC TR 50427 [46] Assessment of inadvertent ignition of flammable atmospheres by radio-frequency radiation.

PD/CLC TR 50427 advises that "Electromagnetic *waves produced by radio-frequency (RF) transmitters, (e.g. radio, television and radar), will induce electric currents and voltages in any conducting structure on which they impinge. The magnitude of the induced current and voltages depends upon the shape and size of the structure relative to the wavelength of the transmitted signal and on the strength of the electromagnetic field. When parts of the structure normally in contact are caused to break or separate momentarily, (e.g. during maintenance or as a result of vibration), a spark may occur if the induced voltage and current is sufficiently large. If this happens in a location where a potentially flammable atmosphere may be present a hazardous situation can occur. However, the possibility of ignition will depend on many factors including whether the spark can deliver sufficient energy to ignite a particular flammable atmosphere.*

Experience gained in practical measurements on structures has shown that for frequencies up to and including 30 MHz, the loop configuration is the most efficient receiving system. At higher *frequencies all structures are large compared with a wavelength and their behaviour is conveniently treated by the use of long dipole theory.*

The generation of a spark is dependent upon the appearance of a small discontinuity in a receiving structure, for example when parts of a structure normally in contact are caused to separate, either during maintenance or at any time by flexing, mechanical vibration or similar actions.

The spark energy required to ignite a flammable atmosphere depends upon the nature and composition of the flammable atmosphere. In making the assessment, it is assumed that the composition is at its optimum for ignition to take place. This in itself provides a margin of safety under most circumstances, since the energy required for ignition of a particular atmosphere generally increases rapidly as its composition moves away from the optimum.

The main frequency range covered in the guide is 9 kHz to 60 GHz. The types of transmitter considered include the following:

a) radio and television broadcast transmitters in specific bands in the range 0,15 MHz to 1 000 MHz;

b) fixed and mobile transmitters for communication purposes, private, commercial and amateur, in specific bands above 0,4 MHz and for military use above 0,15 MHz;

c) radar, in specific bands at 220 MHz, 600 MHz and above 1 GHz;

d) navigational equipment, non-directional beacons, etc., from 9 kHz upwards.

7.4 Overhead pipeline crossings of railway lines

There are a limited number of instances in the UK where there are overhead pipeline crossings of railway lines. If the traction systems are not electrified, then there are no specific issues other than the ones that would be managed by standard pipeline monitoring and inspection procedures carried out in accordance with the pipeline design code requirements and written schemes of examination required under the Pressure System Safety Regulations [47].

If a traction system is to be electrified by either an a.c. or d.c. traction power source, then additional risks will be created. The pipeline operator would need to discuss and agree the appropriate mitigation measures with the railway authorities in a timely manner.

D.C. stray current interference risks are not covered by this TBN. However, in relation to a.c. traction systems there are risks and concerns that need to be addressed in relation to overhead pipeline crossings.

The presence of an electrified system close to an above ground operational pipeline will create a new electrical safety hazard for the pipeline operator. It can also create a touch potential risk for the railway authority and in certain circumstances if the rail pantographs contact the overhead pipeline then the traction system protective devices might not be able to operate, if the pipeline is not effectively earthed. Thus, there will be electrical safety risks that the rail system operator will need to address.

Pipeline operators will need to ensure appropriate signage is present to warn of the electrical risks and anti-vandal and climb protection is in place on overhead pipelines to ensure that a pipeline cannot be used to gain access to the rail power sources. Information on the pipeline owner and emergency contact numbers should be included on the CP or pipeline marker posts close to rail crossings.

Pipeline operators may also in future not be able to gain easy access to a pipeline system following electrification for pipeline inspection or coating repairs. Thus, the requirement to re-coat and inspect a pipeline and pipeline support structures should be considered prior to the electrification of the rail line in a timely manner.

It will be important to establish if there are any flanges or discontinuities in the pipeline system that would create a hazardous area within the vicinity of the rail lines or power sources.

In relation to electrical hazards there will, in the case of a new a.c. traction system, be a touch potential risk on a pipeline at the pipeline rail line crossing point that may be created by any traction system fault current. This touch potential risk would apply to any part of the pipeline or steel work electrically connected to the pipeline within a specified distance of the rail system earth or a rail power system pylon.

BS EN 50122-1 provides guidance on safe distances and maximum touch potential limits. The maximum touch potential is 645V for a fault clearance within 200ms based upon the guidance given in BS EN 50122-1.

In the case of railway systems, the separation distance between metallic structures connected to different earthed systems is greater than the 3m distance typically considered in the pipeline industry and should comply with the rail system operator requirements.

The rail operator should ensure that ground potential rise limits from a fault on an overhead pylon do not result in touch potential risks on the pipeline. This can be achieved by ensuring any new power supply pylons are located as far as practical away from the pipeline.

If a train pantograph was to make contact with a pipeline, then the circuit resistance for any fault needs to be of a sufficient value to enable the protective devices on the a.c. traction system to operate to clear the fault otherwise the pipeline could reach an unsafe voltage for a period of time in excess of the specified clearance time for the rail traction system protective devices.

The pipeline resistance to remote earth must be of a sufficient value to enable the traction system protective devices to operate within the required disconnection time and should generally be less than 1 ohm. In some instances, earthing strips not electrically connected to the pipeline may be installed immediately in front of any pipeline to ensure that should a train pantograph contact with the earth strip then any fault will be cleared.

During normal operations the rail traction system earth voltages can approach voltages up to 25Vrms as advised in BS EN 50122-1, whereas the maximum permitted touch voltage on a pipeline is 15V rms.

If a pipeline was bonded directly to the rail system earth it would also mean that a.c. traction currents can flow in the pipeline and create an enhanced a.c. corrosion risk. Thus, it is not recommended that the pipeline is directly bonded to the rail system earth to mitigate any touch potential risk.

Furthermore, bonding a rail traction system earth directly to the pipeline would have an effect on any pipeline CP system. Thus, not only would the pipeline have an enhanced a.c. interference and. corrosion risk if the rail earth and pipeline were bonded there would also be an enhanced general corrosion risk as effective levels of CP would not be achieved on a pipeline. The CP system would provide current to the pipeline and the rail earth and that would compromise the CP system on a significant length of the rest of the pipeline system either side of the crossing location.

Dependent upon the materials of construction of the traction system earth there may also be an enhanced galvanic corrosion risk on the pipeline, if a direct bond between the two was made.

The use of a direct bond between rail line and pipeline is therefore not recommended to combat touch potential risks.

BS EN 50122-1 section 6.2.1 does permit the use of a Voltage Limiting Device (VLD) between the pipeline and the rail line as an alternative means of discharge of fault current to ensure that the safe touch potential limits defined in BS EN 50122-1 are achieved. The VLD would be connected between the pipeline and the traction system earth. If a VLD is installed it should be maintained in accordance with the manufacturer's guidance. These devices can fail short circuit and result in direct contact with a pipeline and rail earth. The latter risk needs to be evaluated and where they are employed remote monitoring devices should also be installed.

The VLD must have Railway Authority certification for use on the applicable voltage circuits. The spark over voltage would generally be in the region of 220V, which is below the maximum touch potential limit and the working voltage of VLD devices would generally in the region of 75V. The device must be capable of carrying the expected fault current at the relevant location.

Figure 12 shows a picture of a typical VLD for connection between pipelines and rail system earths, whilst the typical electrical characteristics of a device are given on Table 5.

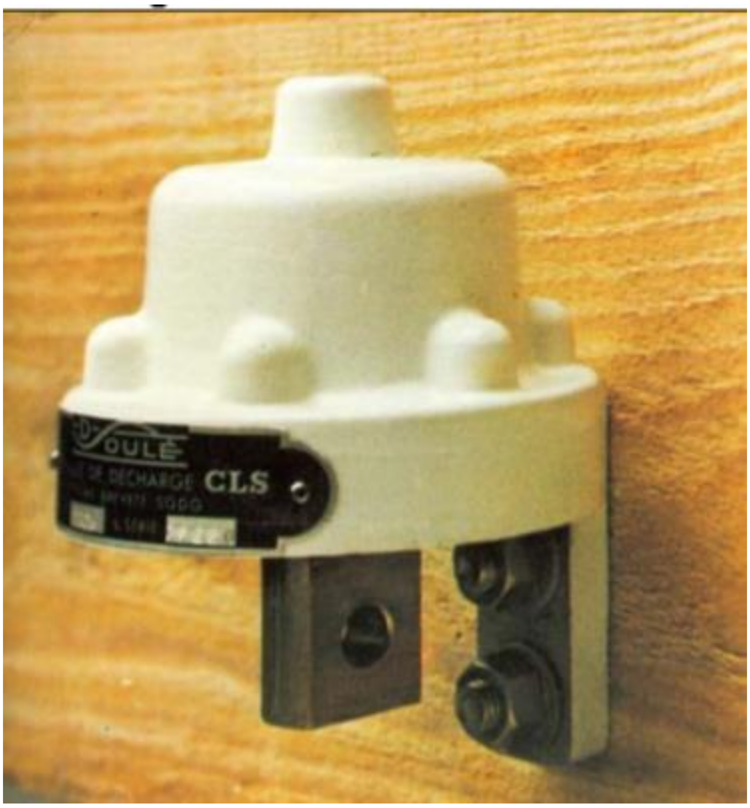


Figure 12 Typical voltage limiting device employed to discharge current to earth on a.c. traction systems

Consideration should be given to the use of a remote monitoring device to ensure that the pipeline to soil potential and a.c. coupon current can be recorded. A remote monitoring device could warn of inadvertent contact between the rail earth and the pipeline.

Any cable used to carry fault current should have a sufficient conductor size to accommodate the projected fault current with suitable derating factors employed to size the conductor.

There should ideally be two pipe connections at any VLD location and the current capability of the cable suitably de-rated dependent upon the installation method. One cable should be used for potential measurement and the other for fault current as cables used for fault currents would be of a larger conductor size than the potential measurement cable.

It should be noted that in the UK the rail authorities use aluminium rather than copper earths and aluminium conductor cross section area typically in the region of 150mm sq. for earthing purposes.

Parameter	Value
Working voltage	**75 V AC**
Withstand voltage	**150 V AC**
Maximum sparkover voltage	**220 V AC**
Maximum leakage current under working voltage (mA)	**50**
Short duration flow capability (A / s)	**8 000 / ---**
Continuous flow capability (A / 30 min)	**4 000**

Table 5 Typical voltage limiting device characteristics for use on 25kV traction systems

7.5 Use of decoupling devices at I/Js in AGI's

Decoupling devices include Kirk cells, PCRs, SSDs and OVPs and additional information on the use and construction of these devices is given in Appendix C of this TBN.

If PCR's for example are employed at AGI's to mitigate a.c. interference on a pipeline and provide surge protection across I/J's there are specific electrical safety risks that pipeline operators need to be aware of. Additional information on the use and construction of PCRs is given in Appendix C of this TBN.

Decoupling devices installed at AGI's can discharge a.c. current to the site earth across I/Js. This is because PCR's or similar decoupling devices capacitively couple a pipeline to an AGI earth. If the site earth has a low impedance, then the magnitude of a.c. current discharge through the PCR could be significant and can typically vary between 1 to 40 A. The higher the levels of a.c. interference on a pipeline system the higher will be the level of a.c. current discharge through a decoupling device.

The use of a decoupling device across an I/J will mean that the pipework within an AGI will be capacitively coupled to the pipeline. Thus, any high voltage fault arising on the pipeline will be transferred to the AGI earth and vice versa. In some instances, this can result in a low a.c. voltage 2V to 10V being normally present on the AGI earth. The higher the AGI earth system resistance to remote earth the higher the long-term a.c voltage levels on the AGI earth.

This can result in an incendive ignition risk, if earth cables or pipework are disconnected and can affect instrumentation.

If the pipework within an AGI is electrically connected to the AGI fence, then any touch potential on the pipeline created during long term or short-term interference events will also be transferred to the AGI fence. In such a situation the fence should be coated, and warning signs installed to advise of the additional touch potential risk to personnel in contact with the fence AGI fence or within 3m of it. In AGIs it is prudent to have the fence electrically isolated from the AGI earth and at least 3m separation between the fence and any other earthed structure within an AGI.

If a decoupling device is connected across an I/J, then the AGI pipework will have a.c. current flowing in the above ground and buried pipework close to the I/J. There may also be a.c. current flowing in the site earthing. The closer a section of pipework is to an I/J the greater the magnitude of a.c. current flow. There may be a spark hazard on disconnection of pipework in such a situation and the risk should be evaluated. The spark risk should be evaluated when any pipework is to be disconnected.

The spark energy is dependent upon the circuit inductance and the square of the current flowing.

Suitable warning signs should be placed by decoupling devices to warn of the spark risk on cable or pipework disconnection. Currents of up to 40A can flow through the devices on pipelines affected by. significant levels of a.c. interference and there may be a spark produced if the cables connected to a PCR device or the I/J's are disconnected in such a situation.

Disconnection of decoupling device cables across I/J's should only be carried out under a hot work permit if an I/J or I/F is in a hazardous area. The current flow through any decoupling device should be recorded as part of the routine monitoring on a pipeline CP and a.c. mitigation system.

It is important to ensure any decoupling or surge protection device has the required ATEX certification for the location in which it is installed and is rated to carry the maximum fault current that is likely to be experienced. The cable length connected to each device should be minimised and be of sufficient length to ensure that the hazardous area certification for any decoupling device is not compromised.

It should be noted that some pipeline operators do not permit the use of PCR's or SSDs installed in earthing circuits as they can be considered as switching devices. BS 7671 does not permit switching devices in earthing circuits. If a PCR or SSD is to be used in an earthing circuit its use must be approved by the discipline electrical engineer.

Zone 2 certified PCRs and SSDs do not have protective covers across the respective terminals and there is spark risk on inadvertent short circuit of bare terminals and operators should consider how this risk can be mitigated and reduced. Operators should ensure that access to the bare exposed terminals is restricted so that the latter risk can be mitigated. The Zone 1 certified devices have the connection terminals contained within an EExd enclosure and thus do not have a spark risk upon inadvertent short circuit

In AGI's the earthing system should either be a TN-S or TT system to comply with the guidance given in BS EN 60079-14 [48].to ensure that there is no a.c. current flow in earthing cables e.g. due to neutral currents.

The use of a PCR or SSD connected across an I/J may cause a.c. current to flow in the site earthing system and counteract the reason for the use of a TN-S or TT earth system i.e. to ensure no a.c current flow in earthed connections. Thus, there may be a.c current flowing in the site earthing, which is a risk electrical personnel would not expect with a TT or TN-S earthing system.

Where PCRs or SSDs are employed across I/Js or I/Fs the electrical engineer responsible for the AGI should be advised, so that the appropriate risk mitigation methods can be employed, and electrical personnel can be advised on the enhanced incendive ignition risk on disconnection of earth cables or pipework.

Where PCRs or surge protection devices are installed, they should be inspected in accordance with BS EN 60079-17 [49] at regular intervals.

7.6 I/J's at AGIs without decoupling devices installed

If a pipeline system is susceptible to a.c. interference and no decoupling device is connected across an I/J or I/F, then there could be an a.c. voltage difference across an I/J or I/F. The a.c. voltage difference would be in addition to the d.c. voltage difference created by the pipeline CP system. There would exist two spark hazard risks one from the d.c. voltage present across an insulating device from the CP system and the other from the a.c. voltage each side of an I/J.

If a surge protection spark gap device is fitted this would not act as a decoupling device and an a.c. and d.c. voltage difference could exist each side of an I/F or I/J

Personnel should be aware of the risk as inadvertent connection across I/J's e.g. via tools or scaffolding can result in a spark risk and measures should be adopted to mitigate inadvertent contact.

These measures would include coating of the I/J and I/F with a cold applied laminate tape to avoid inadvertent short circuits and the installation of signs warning of the nature of the hazard.

In the case of above ground, I/F's or I/J's at pig traps then there may be a risk of inadvertent short circuits when temporary scaffolding is erected for pigging operations for example or when a pig passes across the I/J when there is an appreciable a.c voltage difference across an I/J.

On pipelines susceptible to a.c. interference the magnitude of the long term a.c. voltage difference across insulating devices should be confirmed as part of any evaluation of a.c. interference. In some cases, 20 to 30Vrms may be present and significant current may be available and would pose a spark and incendive ignition risk due to the available energy (see Figure 13).

Figure 13 Spark risk on short circuit of I/J with a.c. voltage present

Operators should note that for testing I/F’s and I/J’s there is a device that uses radio frequencies to determine the effectiveness of flange insulation on cathodically protected pipelines. Care should be exercised when using such a device on pipelines affected by a.c. interference, as the device terminals have a low impedance and when connection is made across a flange a spark may occur, as the a.c. current can discharge through the device.

Personnel are often not aware of the limitations with this type of device when using it to test insulation resistances on I/Js or I/Fs on pipelines affected by a.c. interference, as the risk it is not advised in the manufacturers data sheet. An example of such a risk is given in Figure 14.

.

Figure 14 Spark risk on testing I/F with high frequency insulation flange tester with a.c. voltage present

Any work carried out when testing I/F’s and I/J’s installed in a hazardous area using flange insulation testers should be carried out under a Hot Work permit unless and intrinsically safe multimeter is employed.

7.7 Use of PCRs or SSDs to isolate earthing systems from pipelines

Some pipeline operators use Kirk Cells, PCRs or SSDs to d.c. isolate pipelines from copper or similar earthing systems. The PCR device is placed in series with the cathodically protected pipeline and earthing network.

The PCR must be suitably rated to withstand the prospective fault current and if located in a hazardous area must have the appropriate certification for the Zone, gas group and area temperature classification.

Any interconnecting cable should be able to take the fault current without excessive voltage loss. Cable lengths shall be as short as possible.

It should be noted that some pipeline operators do not permit the use of decoupling devices in earthing circuits as they can be classed as switching devices and BS 7671 does not permit the use of switching devices in earthing circuits.

The decoupling devices are claimed by the manufacturers to fail short circuit but if a PCR or SSD was to fail open circuit it could mean that the earthing arrangement will be compromised.

Pipeline operators’ electrical engineers should approve the use of d.c. decoupling devices in earthing circuits where they are used to electrically isolate earthing systems from pipelines so that the CP systems are not compromised.

7.8 Above ground pipelines

If an above ground pipeline system is susceptible to a.c. interference and no PCR is connected across an I/J or I/F, then there could be an a.c. voltage difference across the I/J in addition to the d.c. voltage difference caused by the pipeline CP system; the a.c voltage would exist due to capacitive coupling.

Pipeline operators should review the risks of capacitive and inductive coupling in such situations. One of the risks would be that high voltage power line cables if they cross a pipeline could fall onto a pipeline and if the pipeline is not effectively earthed the power cable protective devices may not operate.

It is essential that above ground pipelines are effectively earthed to follow the guidance in this TBN and the Energy Institute Model Code of Safe Practice Part 1. The electrical Safety Code advises that unless adequately connected to earth elsewhere all metallic and process utility pipelines should be bonded to a common earth conductor by means of earth bosses or pipe clamps and be connected to the earthing system at all points where they enter or leave a hazardous area.

All above ground pipework should have a resistance to remote earth of at least 10 Ohms. However, some operators do have lower resistance to remote earth requirements. It is not necessary to bond across flange joints unless the earth resistance from any point is less than 10 Ohms

7.9 Permissible voltage limits I/J's

I/J's can be damaged if exposed to high voltage surges and the insulation properties of the device affected.

BS EN 50443 states in relation to damage to pipeline systems by high voltage strikes.

The interference voltage, (r.m.s. value), between the metallic pipeline system and the earth at any point of the pipeline system, or the interference voltage, (r.m.s. value,) between any element of the electric/electronic equipment connected between the metallic pipeline and the earth, shall not exceed 2 000V;

The voltage difference (r.m.s. value) across an insulating joint shall not exceed 2 000V.

Values greater than 2 000 V can be accepted if the plant is able to withstand such values and if there is an agreement on that

Thus, 2000V is the maximum voltage that is permissible at an I/J based upon the guidance in BS EN 50443.

Prior to installation new I/Js should be subjected to a 500V test and the insulation resistance should exceed 5M Ohms.

I/Js can be bridged internally by metallic debris and the insulation resistance compromised. The internal surfaces of I/Js should be coated.

The use of metallic based paints should also be avoided to coat the external surfaces of an I/J to prevent resistive short circuits.

7.10 Static electricity

In the case of pipeline systems there are certain situations that can create a static electrical risk. BS 5958-1 [50] and PD CLC/TR 60079-32-1:2015 [51] provide guidance on electrostatic hazards in hazardous areas

Electrostatic hazards can be created by Holiday detection operations particularly on 3-layer polyethylene coatings or similar coatings with a high insulation resistance or by grit and shot blasting operations during construction.

High voltages up to 30 kV can be present, which would not create a shock risk because of the limited current available but may result in an involuntary action leading to injury. Voltages can remain for a period of time after Holiday detection operations particularly if the pipeline is not earthed.

Safe discharge of static electricity can be achieved by ensuring a resistance to earth of less than 1 M Ohm in certain circumstances where items are fabricated from conductive or anti-static materials. However, in the case of pipelines BS 5958-1 recommended that the resistance to earth is less than 10 Ohms.

BS 5958-1 has now been withdrawn but did general guidance on prevention of static discharge from clothing and from nonconductive liquids. Guidance on control of undesirable effects of static electricity for particular situations was also given in BS 5958-2 [52], with Section 19.0 providing specific guidance in relation to pipelines. The guidance given however is still considered applicable.

Instances that can create a static risk during construction are static electrical discharge from clothing or from shot and grit blasting operations during pipeline construction that can ignite flammable products. Thus, shot blasting and pipe coating operations should be separated by at least 30m.

Correct PPE should be worn in areas where there is a risk of ignition due to electrostatic discharge should comply with the requirements of BS EN ISO 20345 [53],

PD CLC/TR 60079-32-1 gives guidance on situations where an electrostatic hazard may exist e.g. tank cleaning operations, paint and coating application, flow of low conductivity fluids in pipelines and fuel loading operations.

Basic information about the generation of undesirable static electricity in solids, liquids, gases, explosives, and also on people, together with descriptions of how the charges generated cause ignitions or electrostatic shocks, is given in the annexes and in PD IEC/TR 61340-1 [54], The Energy Institute Model Code of Safe Practice Part 21 [55] also gives additional guidance on the control of static electrical hazards in the oil and gas industry.

Spark hazards in relation to pipe systems on fuel loading jetties are also identified in ISGOTT [56],

7.11 Coating voltage limits

NACE SP 0177 does give guidance on permissible coating stress levels. NACE SP 0177 identifies that limiting the coating stress voltage should be a mitigation objective. Expected threshold values for coatings differ with type and are generally considered to be in the range of up to 2 kV for tape wraps and coal tar enamels and 3 to 5 kV for fusion-bonded epoxy (FBE) and polyethylene coatings for a short duration fault.

7.12 Casings (Sleeves)

NACE SP 0177 give guidance on casings, typically referred to as sleeves in the UK. In relation to a.c. interference and states". Bare or poorly coated casings may be deliberately connected to a coated structure through a d.c. decoupling device to lower the impedance of the structure to earth during surge conditions and to avoid arcing between the carrier pipeline and the casing.

Thus, if there is a cased crossing on a pipeline at a location where a high touch potential may occur as a result of a substation fault or a power line cable fault in an air-filled sleeve there would be the possibility of an arc between the pipeline and casing. This could on thin walled pipe result in perforation or damage to the carrier pipe. Pipeline operators should identify locations where

The use of the decoupling device would prevent an arc between the two structures and may need to be considered where such situations exist e.g. where there are cased crossings close to HV pylon towers or at or near substations.

Arcing between carrier pipelines and sleeves can occur and the risk can be mitigated by the use of a decoupling device connected between the carrier pipeline and sleeve.

A schematic representation of a mitigating arc risks between pipelines and casings is shown in Figure 15.

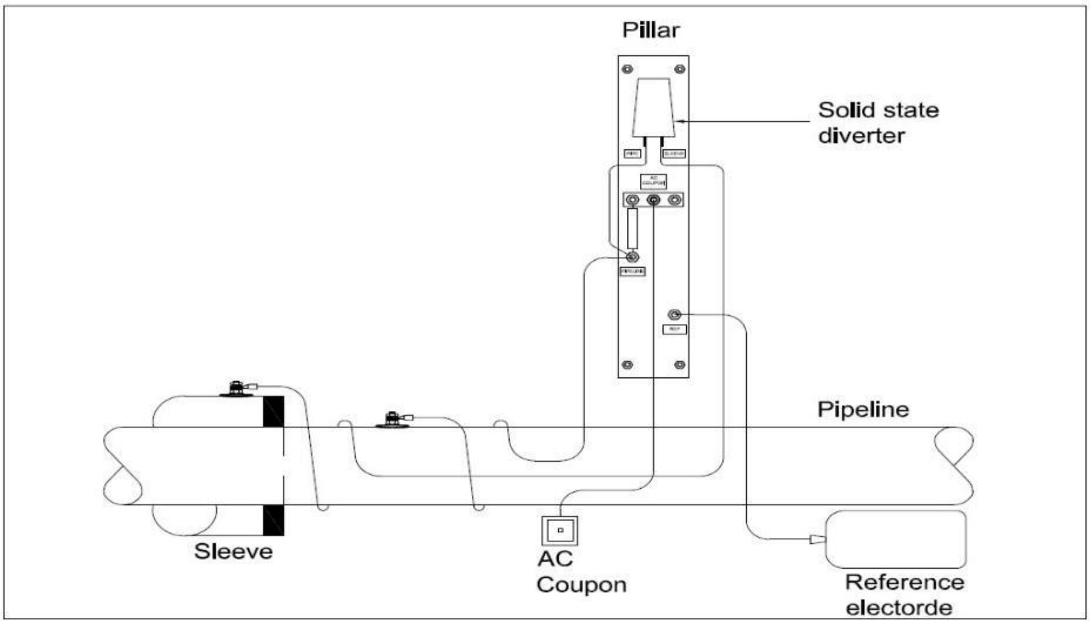


Figure 15 Mitigation of arc risk on pipeline within sleeve

High risk locations for arcing are where there is a sleeve crossing close to a power line tower or near a HV substation. Such mitigation measures should only be considered at locations where a high voltage may exist during a fault condition that could result in arcing and damage to the carrier pipe.

7.13 Flash over situations

There have been reported situations where flash overs between overhead power lines and pipelines have occurred resulting in pipeline damage, i.e. metal loss. This is discussed in the Canadian Energy Association Publication referenced in Section 8.0. Mitigation of arcing risks to pipelines, due to faults at adjacent power line structures, is also discussed by Fielstch and Winget [57].

In order to ensure there is no risk of arcing, a “safe” separation distance between the pipeline and any part of the power line tower foundation or grounding system must be maintained. Fielstch and Winget discusses how to determine the “safe” separation distance that is required based on research, literature and standards, and explore mitigation options in circumstances where this “safe” distance cannot be feasibly maintained. Calculations and mitigation measures from several case studies are presented by Fielstch and Winget.

In one case in the UK flashover between an overhead power line and pipeline occurred because crops were burnt underneath a power cable. The change in the electrical properties of the air as result of the smoke from the crop burning operation caused the power line to arc to earth. The arc resulted in localised melting of the pipeline metal and loss of wall thickness, (see Figure 16).

Figure 16 Damage to buried pipeline as a result of arc strike

Although the probability of a phase to ground fault occurring at a specific transmission power line tower and resulting in an arc to an adjacent pipeline may be quite small, the risk cannot be ignored due to the severity of the potential consequences. A sustained arc to a pipeline can result in melting of the pipe wall and catastrophic failure of the pipeline.

The arc strike shown on Figure 16 resulted in damage to a CP T/R unit a few kilometres away from the arc location and the damage to the T/R unit is shown on Figure 17.

Figure 17 Damage to CP T/R unit as a result of arc strike on pipeline

The arc strike shown on Figure 17 occurred as a result of vegetation being burnt in a field underneath. HVAC overhead powerlines. The carbon particles from the crop burning operations changed the conductive properties of the air and current arced to ground. The current caused damage to a buried pipeline close to the powerlines.

It is therefore important that where pipelines are close to powerlines that farmers are warned of the potential risk and also personnel undertaking vantage point patrols on pipelines are aware of the possibility of damage to buried pipelines by crop burning operations.

As far as the authors of this publication are aware the HSE have not published guidelines on fires within the vicinity of HV powerlines. However, Powerlink Queensland [58] has published guidance on fire safety near power lines.

7.14 Work on CP system groundbeds

Groundbeds can act as earths to discharge fault currents off a pipeline. In such a situation the fault current would discharge through the transformer rectifier and result in damage to the transformer rectifier

If a new groundbed is being installed or a groundbed is being replaced, then operatives should disconnect the CP positive cable at the CP TR Unit to ensure that no fault current can flow to earth through the groundbed, whilst the works take place. Groundbed replacement could take place over a number of days and thus the period of time workers could be exposed to a risk could be significant and possibly exceed a tolerable level. The level of risk would be dependent upon the T/R unit construction and the circuit protection installed in either the d.c. negative or positive output connections.

Where a d.c. output fuse is installed on a T/R unit and is not bypassed by any varistors or surge protection devices then the fuse should over protection to over current surges. However, there is no circuit protection then personnel could be exposed to a significant touch and step potential risk when working on groundbeds.

Figure 18 shows an approximation of the voltage earth potential rise at a CP system groundbed during fault conditions.

Disconnection of either the positive and negative cable or both at the TR unit would mitigate the risk.

It should also be noted that disconnection of the negative current carrying cable at a TR unit may not in all cases mitigate the shock risk to personnel working on T/R units if there is a potential measurement connection present or connection to a remote monitoring system. This is because in the event of high voltage surge with a reference electrode present a potential measurement connection then a voltage surge could occur on the potential measurement connection.

Any reconnection of the cables to CP TR units should be supervised and checked by CP Engineer to ensure that there is no risk of a reverse polarity connection on reconnection.

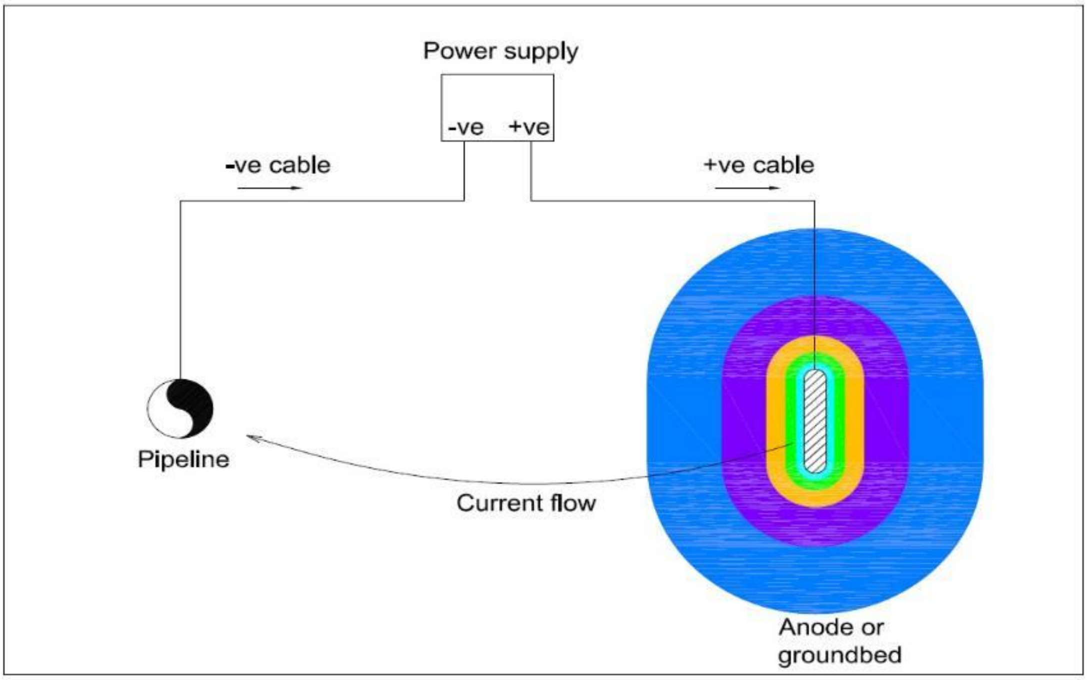


Figure 18 Schematic representation of earth potential rise at groundbed during fault conditions

7.15 Electrical equipment on pipeline construction sites

Electrical equipment used on pipeline construction sites must comply with UK regulatory authority legislation and guidance notes.

The legal requirements relating specifically to the use and maintenance of electrical equipment are contained in the Electricity at Work Regulations 1989. These regulations apply to all work activities involving electrical equipment. They place duties on employers, the self-employed and employees (subsequently referred to as 'duty holders').

These duties are intended to control risks arising from the use of electricity. The Regulations require that electrical systems and equipment must be maintained, so far as reasonably practicable, to prevent danger. This requirement covers all items of electrical equipment including fixed or portable equipment. HSG 107 [59] provides guidance on the maintenance of portable and permanent equipment, whilst BS 7671 specifies the testing requirements and nature and frequency of the tests.

HSG 85 [60] covers the key elements to consider when devising safe working practices and is for people who carry out work on or near electrical equipment. It includes advice for managers and supervisors who control or influence the design, specification, selection, installation, commissioning, maintenance or operation of electrical equipment. Particular attention should be paid on construction sites to welding and similar operations where a 3-phase supply is used to power electrical equipment.

Suitably rated Earth Leakage Circuit Breakers should be installed between the electrical equipment and the a.c. power source. The electrical installation should be tested by a competent electrician.

7.16 Spark hazard on isolation of CP systems

The EI Electrical Safety Code Part 1 recommends that before any bond or pipework is disconnected that a period of time in excess of 24 hours should be allowed after the CP system has been switched off to enable the CP system to polarise and the stored energy to decay before bonds or pipework are disconnected.

It should be noted that if there is a PCR or similar decoupling device connected across I/Js or if the pipework is connected to an earthing system that is not a TT or TN-S system then there may be a.c current flowing in pipework even if the CP system has been isolated. Thus, the possibility of current flow from all sources needs to be considered when mitigating the spark risk by isolation of any CP system.

The possibility of current flow in pipework from all possible sources should be considered before any pipework or earth cables are disconnected. The Energy Institute guidelines on earthing and bonding [61] give information in relation to earthing of above ground pipeline systems.

7.17 Hazardous areas on offsite pipelines and pipework

Where there are flanged joints on cross country or offsite pipelines these may create hazardous areas. The hazardous area would be generally classed as a Zone 2 area. Hazardous areas are classified into zones based on the frequency of the occurrence and the duration of an explosive gas atmosphere. In the case of a secondary release, the relevant zone is Zone 2 and is defined as a place where an explosive atmosphere is not likely to occur in normal operation but, if it does occur, will persist for a short period only. In areas where the ventilation can be regarded as 'high' relative to the leak size, BS EN 60079:10 [62] recommends that the area classification is Zone 2 but of negligible extent (NE) such that no action is thus required to control sources of ignition within it.

Pipeline operators should identify locations on cross country or offsite pipeline routes where hazardous areas may exist and access by the general public is possible. This is so that appropriate risk assessments can be made in accordance with DSEAR.

Experience has indicated that there are sometimes locations on offsite pipelines where there are flanged joints and the public has access to these and a hazard exists. If an ignition source was to be present, there could be an incendive ignition risk in certain circumstances and a safety risk.

7.18 CCTV systems and electrified fences

Electrified fences and CCTV have been installed around AGIs to provide enhanced security in such situations the CP system may be affected, if any additional earthing is installed and the touch potential risks would need to be assessed to ensure any new monitoring, cameras or electrical system equipment does not compromise existing arrangements.

Electrified fence may exist on cross country pipeline routes and could pose a risk to CIP survey crews if the survey wire was to make contact with an electrified fence. Any electrical contact between the survey wire and a fence is not likely to provide a fatal electrical shock risk but could result in an involuntary action. There have also been situations were CIP surveys have been conducted over undulating terrain and CIP survey wire could contact LV overhead power cables and also pose a risk. The risks in these situations should be assessed.

7.19 Pipeline CP system T/R units

The CP system T/R units should be subjected to the routine electrical inspection tests detailed in BS 7671 at periodic intervals as agreed by the Operator's electrical competent person. The test should include confirmation of ELCB operation, earth loop impedance and cable insulation checks.

Only electrically competent personnel should perform checks on the a.c side of the transformer rectifiers. Voltsticks are sometimes used to confirm that there is not a hazardous voltage present on the transformer rectifier frame before any access to the controls or meters.

The EI Electrical Safety Code recommends that safety isolating transformers to BS EN 61558-1 should be employed on transformer rectifiers. This is to mitigate the risk of the mains voltage being transferred to the d.c. output terminals. However, it should be noted that most CP T/R units do not have the safety isolating transformers installed as a matter of course.

The d.c. output voltage on CP TR units should not exceed 50V for electrical safety. Where CP system d.c. output cables from T/R units pass through hazardous areas it is advisable to have a two-pole isolator fitted to ensure that the d.c. output can be isolated for safety purposes.

8. REFERENCES

[1] BS EN 50443-2011 Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems.

[2] BS EN ISO 18086- 2017 Corrosion of metals and alloys. Determination of AC corrosion. Protection criteria (withdrawn)

[3] UKOPA/GPG/005 AC Corrosion on Pipelines

[4] BS EN 15280- 2013 Evaluation of a.c. corrosion likelihood of buried pipelines - Application to cathodically protected pipelines.

[5] NACE SP 21424-2018 Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring

[6] BS EN 50162-2014 Protection against corrosion by stray current from direct current systems

[7] ISO 21857 - Petroleum, Petrochemical and natural gas industries. - Stray Current Interference on Pipeline Systems,

[8] AS/NZS 4853:2012 Electrical hazards on metallic pipelines.

[9] The Australian Pipeline Industry – “Guidelines for Electrical Hazards” Version 2 15/1/14.

[10] CAN/CSA-C22.3 No. 6-M91 Principles and Practices of Electrical Coordination Between Pipelines and Electric Supply Lines

[11] NACE SP0177- 2014 Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

[12] BS EN 12954-2001 Cathodic Protection of buried or immersed metallic structures – General principles and Application for pipelines.

[13] Canadian Energy Pipeline Association “AC Interference Guideline Final Report - June 2014.

[14] CIGRE TB 95 Guide on the influence of high voltage a.c. power systems on metallic pipelines.

[15] INGAA Foundation Report 2015-04 Criteria for Pipelines Co-existing with Power Lines

[16] Energy Institute (EI) Model Code of Safe Practice Part 1- 2010: The selection, installation, inspection, and maintenance of electrical and non-electrical apparatus in hazardous areas ISBN 9780852935583

[17] The Electricity at Work Regulations 1989- Statutory Implement 1989/635

[18] BS 7671: 2018 Requirements for Electrical Installations. IET Wiring Regulations Eighteenth Edition.

[19] Construction (Design and Management) Regulations 2015- Statutory Implement 2005/15

[20] BS EN 50522-:2010 Earthing of power installations exceeding 1kV.

[21] Private communication H Liddell ERM Ltd to P Lydon IACS Corrosion Engineering Ltd. May 2018

[22] PD IEC/TR 60479-1- 2005 +A1 2016: Effects of current on human beings and livestock- General Aspects.

[23] PD IEC/TR 60479-4 2011 Effects of lightning strokes on human beings and livestock- Effects of Lightning strokes.

[24] BS EN 50122-1:2011+A4:2017 Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Protective provisions against electric shock.

[25] Private communication M Coates RINA Ltd to P Lydon IACS Corrosion Engineering Ltd. June 2018

[26] BS 7430-2011 + A1 2015 Code of practice for protective earthing of electrical installations

[27] Electricity Networks Association Technical Specification 41–24 Guidelines for the design, Installation, Testing and Maintenance of Main Earthing Systems in Substations.

]28] HSE Guidance Note GS 38" Electrical test equipment for use on low voltage electrical systems published by HSE Books 4th Edition 2015

[29] BS EN 61010-1:2010 Safety requirements for electrical equipment for measurement, control, and laboratory use. General requirements

[30] HSG 47 Avoidance of Danger from buried services ISBN 978 0 7176 6584 6.

[31] GS 6 Avoidance of Danger from Overhead power cables. Published by HSE Books 4th edition

[32] ENA TS-43-8 Issue 3 - 2004 Overhead Line Clearances.

[33] S Karanth SARK Projects Ahmedabad India private communication with P Lydon.

[34] ROSPA Lightning at Leisure https://www.rospa.com/leisure-safety/advice/lightning/

[35] OHSA Fact Sheet Lightning Safety When Working Outdoors OSHA - DTSEM FS-3863 05/2016

[36] BS EN 62305-2:2012 Protection against lightning. Risk management

[37] The Health and Safety at Work Act 1974- Statutory Implement 1974/37

[38] BS EN 62305-3 -2011 Protection against lightning Part 3: Physical damage to structures and life hazard

[39] ISO 3864-2011 Graphical Symbols – Safety colours and safety signs – Part 1 Design principles for safety signs and safety markings

[40] The Management of Health and Safety at Work Regulations 1999- Statutory Implement 1999/3242

[41] CIGRÉ TB 290 A.C. Corrosion on Metallic Pipelines due to Interference from A.C. Power Lines - Phenomenon, Modelling and Countermeasures.

[42] IGEM/TD/1. Edition 5 Steel pipelines and associated installations for high pressure gas transmission

[43] PD 8010-1 -2015 + A1 2016 Pipeline systems – Part 1: Steel pipelines on land – Code of practice

[44] BS EN ISO 15257-2017 Cathodic protection. Competence levels and certification of cathodic protection personnel

[45] Energy Institute Model Code of Safe Practice Part 1: The selection, installation, inspection, and maintenance of electrical and non-electrical apparatus in hazardous areas 8th Edition June 2010 ISBN 9780852935583

[46] PD/CLC TR 50427- 2004 Assessment of inadvertent ignition of flammable atmospheres by radio-frequency radiation. Guide.

[47] Pressure System Safety Regulations 2000 Statutory Instrument 2000 No 128.

[48] BS EN 60079-14: 2014 Explosive atmospheres. Electrical installations design, selection and erection

[49] BS EN 60079-17: 2014 Explosive atmospheres. Electrical installations inspection and maintenance.

[50] BS 5958-1:1991 Code of practice for control of undesirable static electricity. General considerations (withdrawn)

[51] PD CLC/TR 60079-32-1:2015 Explosive atmospheres. Electrostatic hazards, guidance

[50] BS 5958-2:1991 Code of practice for control of undesirable static electricity. Recommendations for particular industrial situations (withdrawn)

[52] BS EN ISO 20345:2011 Personal protective equipment. Safety footwear

[54] PD IEC/TR 61340-1:2012 Electrostatics. Electrostatic phenomena. Principles and measurements

[55] Energy Institute Model Code of Safe Practice Part 21: Guidelines for the control of hazards arising from static electricity Feb 2013 3rd Edition ISBN 9780852936368

[56] ISGOTT International Safety Guide Oil Tankers and Terminals 5th Edition June 2006

[57] W Fielstch and B Winget Corrosion 2014 paper 4389 Mitigation of Arcing Risks to Pipelines Due to Phase-to-Ground Faults at Adjacent Transmission Power Line Structures.

[58] Fire and high voltage transmission line safety Powerlink Queensland, PO Box 1193, VIRGINIA QLD 4014 Australia -2015

[59] HSG 107 Maintaining portable electrical equipment

[60] HSG 85 Electricity at work: Safe working practices ISBN 9780717665815

[61] Energy Institute Guidelines on earthing/grounding/bonding in the oil and gas industry 2016 ISBN 9780852939369

[62] BS EN 60079-10-1- 2015 Explosive atmospheres. Classification of areas. Explosive gas atmospheres

[63] BS EN ISO 15589-1 -2017 Petroleum, petrochemical and natural gas industries. Cathodic protection of pipeline systems. On-land pipelines

[64] BS 7361 Part 1 Code of Practice Cathodic Protection (withdrawn)

[65] BS EN 60079-15:2010 Explosive atmospheres. Equipment protection by type of protection "n"

[66] BS EN 60079-1:2014 Explosive atmospheres. Equipment protection by flameproof enclosures "d"

[67] BS EN 62561-3:2017 Lightning protection system components (LPSC). Requirements for isolating spark gaps (ISG)

[68] CIGRÉ TB 347 Earth potential rises in specially bonded screen systems

[69] BS EN 61558-1:2005+A1:2009 Safety of power transformers, power supplies, reactors and similar products. General requirements and tests

APPENDIX A: ABBREVIATIONS

Abbreviation	Meaning
3LPE	Three Layer Polyethylene
A	Amps
AC	Alternating Current
AGI	Above Ground Installation
ALARP	As Low As Reasonably Practical
ATEX	Appareils destinés à être utilisés en ATmosphères EXplosibles.
BS	British Standard
CCTV	Closed Circuit Television
CIGRE	Conseil International des Grands Réseaux Électriques,
CIP	Close Interval Potential
CP	Cathodic Protection
CPR	Cardio Pulmonary Resuscitation
CSA	Canadian Standards Association
DC	Direct Current
DSEAR	Dangerous Substances Explosive Atmospheres Regulations
EI	Energy Institute
ELV	Extra Low Voltage
EN	European Norm
ENA	Energy Networks Association
EPR	Earth Potential Rise
GPG	Good Practice Guide
GPR	Ground Potential Rise
HAZCON	Hazards of Construction
HAZOP	Hazards of Operation
HSE	Health and Safety Executive
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Commission
IET	Institute of Engineering Technology
IGEM	Institute of Gas Engineers and Managers
I/F	Isolation Flange
I/J	Insulation Joint
ILI	Inline Inspection
INGAA	Interstate Natural Gas Association of America
IS	Intrinsic Safety
ISG	Insulated Spark Gap
ISGOTT	International safety Guide Oil Tankers and Terminals

Abbreviation	Meaning
ISO	International Standards Organisation
kA	Kilo Amps
kV	Kilo Volts
LEF	Longitudinal Electric Field
LFI	Low frequency Induction
NACE	National Association of Corrosion Engineers
OHL	Overhead Line
OVP	Over Voltage Protector
PCR	Polarisation Cell Replacement
PD	Published Document
PSR	Pipelines Safety Regulations
rms	Root Mean Square
ROSPA	Royal Society for Protection of Accidents
SGD	Spark Gap device
SSD	Solid State Decouplers
TBN	Technical Briefing Note
TS	Technical Standard
V	Volts
VLD	Voltage Limiting Device

APPENDIX B: USEFUL INFORMATION DEFINITIONS

The definitions applying to this TBN 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.

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.

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.

Counterpoise: buried wires following an a.c. power line from tower to tower. The counterpoise arrangement is often used for reduction of the tower footing resistance in areas with high soil resistivity. Copper or galvanised steel can be used as counterpoise material. When made of copper, the counterpoise may be connected to the towers via spark gaps to avoid galvanic corrosion

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.

DC withstand voltage - value of a D.C. voltage that the ISG can withstand during tests made under specified conditions and for a specified time.

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

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.

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.

impulse sparkover voltage - impulse voltage of the waveshape 1,2/50 to classify the sparkover behaviour of the ISG.

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.

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.

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.

Power frequency withstand voltage - rms value of a sinusoidal power frequency voltage that the ISG can withstand during tests made under specified conditions and for a specified time.

R**ated impulse sparkover voltage** manufacturer's declaration of the ISG sparkover voltage.

Rated withstand voltage - value of a withstand voltage declared by the manufacturer to characterize the isolating behaviour of an ISG.

Rated power frequency withstand voltage - value of a power frequency withstand voltage declared by the manufacturer to characterize the isolating behaviour of an ISG.

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.

Sparkover voltage - maximum voltage value before disruptive discharge between the electrodes of the ISG.

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.

Sparkover voltage - maximum voltage value before disruptive discharge between the electrodes of the ISG.

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 struct**u**re**.**

Transfer potential: A special case of the touch voltage where a voltage is transferred into or out of the substation from or to a remote point external to the substation site.

Transposition: the physical location where the phase conductors are altered or transposed. In one third of the a.c. power line the phase position is U-V-W. In another third of the line the phase position is W-U-V and in the last third of the line the phase position is V-W-U. The reason is that the impedance of a phase conductor depends on the location related to the other phase conductors, earth and shield wires. Resulting from the transposition, the total power frequency impedance of the line will be, in principle, the same for all three phases.

Withstand voltage - value of the test voltage to be applied under specified conditions in a withstand test, during which a specified number of disruptive discharges is tolerated.

APPENDIX C: SURGE PROTECTION ON PIPELINES

C1 Introduction

This Appendix has been produced to provide guidance to pipeline operators on the use of surge protection and d.c. decoupling devices. Surge protection and decoupling devices are installed on some I/Js and I/Fs but not on all pipelines in the UK as part of an a.c interference mitigation system, for safety purposes or to help prevent damage to pipeline insulating devices due to high voltage surges.

Surge protection devices may be installed across insulated flanges or isolation joints to discharge fault current to earth. The fault current may occur as a result of lightning strikes or overhead power line faults experienced by a pipeline.

The surge protection devices can be used to provide protection on pipelines to electrical surges and mitigate the spark risk across I/Fs and I/Js during such events. They also help prevent damage by high voltages to the dielectric materials used to construct insulating gaskets or dielectric fillers on I/Js. Damage to the material can result in loss of insulating properties and affect the performance of the pipeline CP system and ability of an I/J or I/F to electrically isolate a pipeline from other earthed structures. If pipeline I/Fs and/or I/Js need to be replaced this can often be a costly exercise and may require the pipeline to be isolated for a period of time or necessitate a complete cut out operation.

Surge protection devices can also assist in discharging fault current to earth and reduce the voltage levels on a pipeline and mitigate shock to personnel who may come into contact with a pipeline.

If there is a voltage surge on a pipeline this can create a potential difference across pipeline insulation flange faces between the CP Live and Dead side of the insulating device. The pipeline side will experience the high voltage and the dead or non-cathodically protected side of an I/F or I/J would be at an earth potential. Once the voltage exceeds the withstand voltage of the surge protection device then the surge protector will conduct and allow the fault current to be discharged to earth.

For insulated flanges surge protection is primarily provided to ensure that if there is any voltage developed across an insulated flange that it does not approach a value at which a spark will occur between the flange faces or that the insulation device dielectric properties could be affected. Thus, if there was say 2,000 V between the cathodically protected and non-cathodically protected sides of an insulated flange if the air gap between the flange faces was less than a specified distance or there was a resistive connection present across the I/F then the air between the flange faces could be ionised. Current could then flow, and a spark may occur. If the spark was of sufficient energy it could ignite a flammable atmosphere and incendive ignition could occur but only if there was a flammable atmosphere present. The devices that allow the voltage across the flange faces to decay to a safe voltage are termed surge protectors.

A surge protection device installed across the flange faces allows the fault current to be safely discharged to earth before a voltage that could result in arcing was developed across the flange faces. However, sufficient fault current would only be discharged to earth if the resistance to earth on the dead or non cathodically protected side of the flange was of a sufficiently low enough value e.g. less than 10 Ohms to allow current to discharge. If the resistance of the dead side of the flange was higher than 10 Ohms, it would limit the fault current that could be discharged, and the protection device may not be able to limit the voltage level across the insulating device to a safe limit. 7 to 10 Ohms is the minimum resistance to remote earth for lightning protection systems specified by some pipeline operators.

The precise value required for a lightning protection system earth would need to be confirmed by a suitably qualified electrical engineer.

It is important to ensure that in the case of I/Fs and I/Js that the electrical insulation resistance of the device is not compromised by resistive connections caused for example by the use of metallic based paints to coat exposed steel surfaces of I/Js or I/Fs or by metallic cladding installed across an insulating device.

Metallic based paints can provide a lower resistance path across an I/F or I/J for example and in the event of a high voltage surge could ignite and provide an ignition source for any flammable atmosphere. Thus, even if a surge protection device is installed it may not prevent ignition of a paint film and incendive ignition may still occur.

C2 Surge protection devices

There are two surge protection devices that are used on pipelines and these are summarised below:

a) Kirk Cells. which are termed polarisation cells and consist of stainless-steel plates installed in a potassium or sodium hydroxide solution have been historically used on pipelines but have now been replaced by Polarisation Cell Replacements (PCRs) and Solid State Decouplers (SSDs). The latter devices are decoupling devices that block low level d.c. voltages typically in the range +3 V to -3 V but allow a.c. current at any voltage to flow. The precise d.c. blocking voltage capability should be confirmed with the device supplier but a typical value would be -3V to 1V. The PCRs and SSDs allow a.c. currents induced on a pipeline system to discharge across an insulated flange or isolation joint to earth on the non cathodically protected side of the I/F. They can also take substantial a.c. fault currents up to 14kA for 30 cycles at 60Hz, (14kA for 30 cycles at 50 Hz), and lightning current up to 100kA. The older Kirk Cells can take higher fault currents up to 50kA. The PCRs and SSDs have an internal capacitor that allows a.c. current to flow and they have diode/thyristor blocking devices that block the low d.c. voltage but allows a.c. and lighting fault currents to flow. They can be provided to take different fault current levels. In cases in the UK where fault currents in excess of 14kA are required then the Kirk polarisation cells may still be used as they can withstand fault currents up to 50kA. It should be noted that the fault current rating for the devices is lower on 50 Hz a.c. circuits than it is on 60Hz circuits at the higher fault current levels. The fault current capability of the devices does vary. Typically, PCR manufacturers will offer 4 fault current ratings 3.7kA, 5kA, 10kA and 15 kA at 60 Hz or 3.7kA, 5kA, 9kA and 14 kA at 50 Hz. The fault current ratings are those after 30 cycles. The SSD devices typically provide lower fault current ratings in the region of 1.2 kA, 2kA, 3.7kA and 5 kA. The long term a.c. current value through the devices is generally 45A but for PCRs there is an option to provide devices with a long term a.c. current capability of 80 A,

b) Surge protection devices where the surge protector allows conduction of the fault current once the voltage across the device exceeds a given value use spark gap technology. A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air, designed to allow an electrical spark to pass between the conductors. Thus, when the voltage difference between the conductors exceeds the breakdown voltage of the gas within the gap, a spark forms and ionizes the gas allowing current to flow. They do not conduct low voltage a.c and do not act as decoupling devices.

Not all pipeline operators permit the use of surge protection devices at I/F's and I/J's, since some operators are concerned that if a surge protection device is installed across an insulating device the fault current could damage sensitive instrumentation by raising the earth potential within an AGI during a fault to too high a value. Indeed, some pipeline operators design earthing systems at AGIs to have a maximum resistance to remote earth of up to 20 Ohms. In such cases where fault currents are discharged to earth the ground potential with an AGI could rise and reach a level where instrumentation may be damaged or there could be an enhanced touch potential risk within an AGI.

Pipeline operators should agree the use of any surge protection devices in a given situation with the discipline electrical engineer to confirm the suitability of the surge protection device for a given application.

The spark gap devices will not allow low level a.c. current to discharge to earth and will not assist in mitigating long term a.c. interference on a pipeline but will be of benefit in reducing the short-term a.c. interference risk.

Lightning fault currents are relatively short duration faults and are expressed as for example a 10/350 waveform. Thus, 10 relates to the period of time in microseconds before the peak current is reached and the second figure is the period of time in micro-seconds the current will take to decay to half its peak value.

For one commonly supplied spark gap device, the maximum lighting impulse current is stated as 100kA (10/350 µs) and the device has a spark over voltage of less than 1.25kV. The power frequency 50Hz withstand voltage is 250V. the spark over voltage is defined as the maximum voltage value before disruptive discharge occurs between the electrodes of the ISG.

C3 Standard requirements use of surge protection

The relevant standards applicable to the design of CP systems for buried pipelines in the UK are BS EN 12954 and BS EN ISO 15589-1[63].

BS EN 12954 advises in Section 7.2 that *"To avoid damage to isolation joints due to high voltages due to lightning strikes or earth currents caused by electric powerlines, installing protective devices e.g. spark gaps should be considered." If an isolation joint is to be provided with surge protection in hazardous areas, then the spark gap should be suitably certified."*

BS EN 12954 also recommends in Section 7.9 "Cathodically protected structures shall only be connected to a lightning protection system or to a structure bonded to this system through a suitable device e.g. spark gap."

BS EN ISO 15589-1 states" Isolating joints shall be installed in such a manner as to eliminate the risk of accidental shorting. To avoid damage from high voltages due to lightning strikes or a.c. fault currents caused by electric power lines, protective devices shall be considered (e.g. appropriate isolating spark gap, surge protective device, and appropriate electrical earthing)".

Isolating joints installed in areas classified as hazardous in accordance with BS EN 60079-10-1 shall conform to the certification and operational requirements of the hazardous area. Isolating joints shall be provided with accessible test facilities, but no isolation joints are permitted in Zone 0 areas.

BS 7361 Part 1 [64] has now been withdrawn but did give good guidance at the time of its publication on the use of surge protection devices for cathodically protected pipelines. The advice is still considered relevant today

In particular advice in relation to *Intentional or unintentional short-circuit of isolating joints e.g. by tools, or breakdown due to voltage surges on the protected structure induced by lightning or electrical power faults constitute a hazard.*

To avoid the hazard, isolating joints should, if possible, be located outside the hazardous area. Where this is not practicable, measures should be adopted to avoid arcing or sparking. These would include the use of resistance bonds fitted in a flameproof enclosure or located outside the hazardous area, an encapsulated spark gap or surge diverter, or a polarization cell connected across the isolating joint. The surfaces of the isolating joint should be insulated to prevent fortuitous short circuiting by tools."

The EI Electrical Safety Code Part 1 advises that that "That when providing bonding or earthing care should be exercised to shorting out cathodic protection supplies e.g. by making contact between cathodically protected metal work and other earth supplies."

In relation to isolation joints it is stated in the EI Safety Code that "*A spark hazard may be created if unintentional connection is made between impressed current cathodically protected metal work and an earthed structure. Where possible isolating joints should be located in non-hazardous areas. Where this is impossible insulating flanges should be wrapped with a cold applied tape to mitigate against accidental contact (e.g. to short circuiting an isolating flange). In addition, when isolating flanges are provided, the pipework on both sides of an isolating flange should be protected with suitable insulating material for a distance of one metre.*

Intentional or unintentional short circuiting of isolation joints or breakdown due to lightning surge may create a spark having ignition capability. The use of surge protection or appropriate earthing can be used to mitigate against the possibly of sparking across insulating joints."

There is a risk of inadvertent short circuits on PCR and SSD devices if the connection lugs are inadvertently short circuited. The risk occurs on the Zone 2 certified devices as the cable connection terminals are bare and only spaced a short distance apart.

C4 Hazardous area requirements surge protection

Surge protection devices where employed in hazardous areas must be suitable for use in the relevant hazardous area Zone, Gas Group and Temperature Classification for the flammable product that may be present. In the European Union all surge protection devices should have the required ATEX certification and should be rated to carry the maximum expected fault current. The surge protection device cable length should comply with the manufacturers guidance and be as short as possible.

They should also be suitable to ensure that the device will operate before a hazardous touch potential is reached.

It should be noted that where the surge protection device has Exn certification in accordance with BS EN 60079-15 [65] such devices can only be used in a Zone 2 area and not a Zone 1 area. The older spark gap type surge protection devices often only had EExn certification and would not be suitable for use in a Zone 1 area

Any surge protection device for use in a Zone 1 area must have EExd certification in accordance with BS EN 60079-1[66]

It should be noted that Zone 2 certified PCR and SSD devices and Zone 1 and Zone 2 Certified spark gap devices have exposed uninsulated connection points and it is possible to inadvertently short circuit these and create a spark. The terminals in Zone 1 Certified PCRs are not exposed.

Protective covers are not provided by the Manufacturers of such devices, but it is advisable to fit protective covers to the connectors to mitigate the risk of sparking by inadvertent short circuit.

C5 Spark gap surge protection

A surge arrestor is only Ex certified if complete with a specified length of suitably rated cable. It is possible to use longer cable lengths, but these would be special devices and would be made to order.

Surge protection devices can withstand a lighting impulse current of 100kA (10/350 µs) have a spark over voltage of less than 1.25kV. The power frequency 50Hz withstand voltage is 250V.BS EN 62561-3 [67] specifies the requirements for spark gap devices.;

The surge protection device would typically be mounted on brackets the hole sizes of which vary to suit the flange bolt fixing dimensions. The interconnecting cable is a single core 25 mm^2 conductor. This method of fixing enables the surge protection devices to be removed to facilitate testing.

The length of cable connected to each end of the surge protection device must comply with the Manufacturers recommendations. Some devices can be provided cable lengths up to 2m if the cable is connected to the arrestor under factory-controlled conditions. For surge arrestors assembled on site the maximum permitted cable length may be as short as 0.3m.

A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air, designed to allow an electrical spark to pass between the conductors. Thus, when the voltage difference between the conductors exceeds the breakdown voltage of the gas within the gap, a spark forms and ionizes the gas allowing current to flow. The ionisation of the gas reduces the electrical resistance between the conductors so that current then flows until the path of ionized gas is broken, or the current reduces below a minimum value called the "holding current".

This usually happens when the voltage drops each side of the flange and once the voltage source has been removed then the device does not act as switch and there is no current flow. Surge arrestors are not one stop devices i.e. one voltage surge and they fail. They are designed to cope with a number of voltage surges and will still continue to operate. However, the manufacturers cannot precisely quantify how many surges they can withstand as this is due to the discharge current experienced and its duration.

Figure C1 Zone 1 and Zone 2 certified spark gap device

Figure C2 Zone 2 only certified spark gap device

The testing regime recommended surge protection devices should be that described by the manufacturers. The factory acceptance testing for the surge protection devices complies with BS EN 62561-3.

C6 PCR and SSD devices

PCRs or polarisation cell replacements are often employed on pipelines susceptible to a.c. PCRs were introduced in 1994 and the SSDs in 2005. PCR's or polarisation cell replacements are often employed on pipelines susceptible to a.c. PCR's were introduced in 1994 and the SSD's in 2005. SSD's use the same internal construction arrangement as the PCR device but are smaller and also have a lower fault current rating. The fault current rating depends upon a particular manufacturer's range of devices. They consist of electrolytic capacitors to enable long term a.c. current to flow, thyristors to discharge a.c. fault current and a surge protection device to discharge lightning fault currents.

The steady state a.c. current rating for both devices is typically 45A. The circuit diagram for a PCR is given in Figure C3.

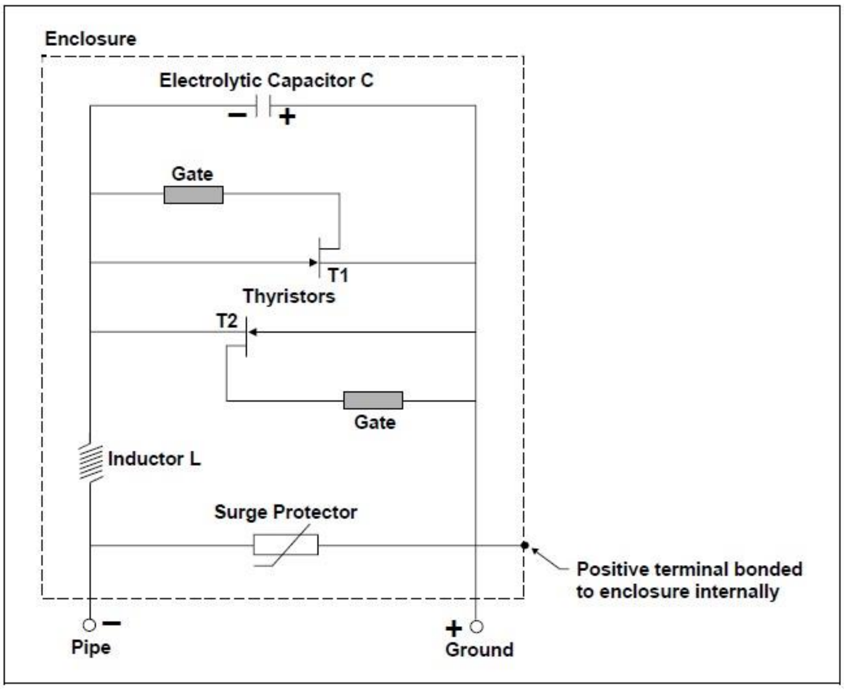


Figure C3 Dairyland PCR circuit diagram extracted from Canadian Energy Pipeline Association Report [7]

PCR and SSD devices have a low internal impedance to the flow of a.c. current with typical values being 0.05 ohms.

Polarity marks (+) and (-) are provided near the terminals to aid in proper installation. Connect the (-) to the structure with CP or more negative structure and the (+) to the grounded, or more positive, system.

The devices can be provided with ATEX Zone 2 or Zone 1 hazardous area certification.

It should be noted that where PCR's are employed across I/J's then the AGI pipework will be capacitively coupled to the pipeline. This creates additional risks and is discussed in section 9.0 of this TBN.

SSDs use the same internal construction. Both products have similar lightning current ratings. Polarity marks (+) and (-) to aid proper installation with -ve connected to structure and +ve to the grounded or more positive system.

Figure C4 Picture of Zone 1 Certified PCR

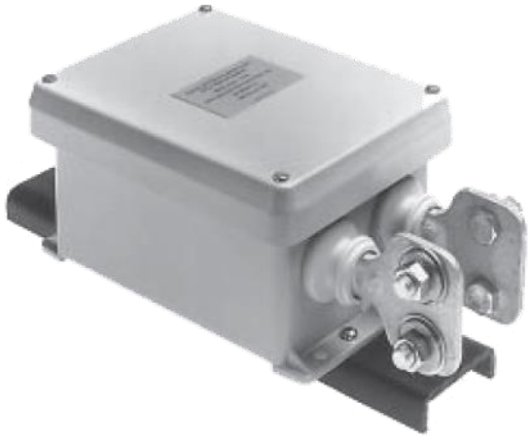


Figure C2 Picture of Zone 2 Certified PCR

The Zone 2 certified devices have bare terminals and there is a spark risk from inadvertent short circuit that operators need to manage.

C7 Insulation device installation

All insulation joints and insulated flanges should be supplied in accordance with an approved specification.

For insulation joints care should be taken to ensure that mechanical damage is not caused during handling and transportation. Weld end preparations should have a protective device to prevent mechanical damage when in transit. The ends of all joints should be sealed to prevent ingress of dirt and moisture.

Ideally the internal surfaces of insulation joints should be coated.

Insulated flanges and joints should be suitable for use at the maximum pipeline design pressure, the design operating temperatures and for the product being transported.

Prior to installation any insulation joint should be bench resistance tested using a 500V insulation tester. The resistance should not be less than 5 M Ohm. Following installation, the joint should be tested using a 500V insulation tester. The resistance should not be less than 5M Ohm. Insulation joints can be damaged by excess heat during installation particularly small diameter joints.

Insulation joints should have cable attachment lugs already fitted where they form part of an approved fabrication. Should the need arise to fit lugs on site then the joint must be kept cool during this operation and when welding into the pipeline. The paint system used to coat above ground I/Js shall not contain any metallic based pigments.

Where joints are installed below ground, they should be built up to a suitable shape with an approved putty then over wrapped with cold applied laminate tape at 55% overlap or should be coated with an approved brush applied multi-component liquid system.

All flange insulation kits shall be supplied in accordance with an agreed specification.

Ensure that the gasket is suitable for use at the minimum and maximum temperature ranges and for the type of flange e.g. whether weld neck or slip on. Flange bolts on insulated flanges should be 12mm longer than those normally supplied for the flange class to allow for the extra thickness of the gasket and insulating washers.

The flange bolt tightening torque should be confirmed by the gasket manufacturer as it is invariably lower than that for flanges without gaskets installed. The gasket supplier’s installation instructors should be followed for I/F installation especially in relation to bolt tightening sequence.

The bolt insulating sleeves should be of the required length. It should be noted that where a surge protection device is installed across a flange face then the insulating sleeve length may need to be slightly longer than normal to accommodate any surge arrestor fixing brackets.

Using a multimeter set to the resistance or continuity scale or 500V earth megger should be used to check the insulation resistance of all bolt ends for non-continuity with both sides of flanges. The values should be recorded. The flange to flange resistance should also be recorded.

Where sited above ground the gap between flanges should be filled with approved putty, primed and taped over to the edge of the flange using an approved tape, the remainder should be painted as appropriate.

Insulated flanges should not be installed below ground.