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Title: **GUIDELINE ON THE ELECTRICAL CO-ORDINATION OF PIPELINES AND POWER LINES**

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1. Introduction

When a metallic pipeline is located in close proximity to power lines, there are several important issues to consider by both the electrical utility and the pipeline operator. During a power line fault, very high pipeline voltages can result from inductive and conductive coupling, which can damage the cathodic protection systems, rupture the coating and present a significant safety hazard for maintenance personnel. During normal operation, the pipeline voltages will be lower but can still present a safety hazard due to the extended duration, and can result in AC-induced corrosion of the pipe wall.

From Eskom’s perspective, an added concern is that the d.c. potentials of the pipeline’s cathodic protection system can produce leakage currents on power line structures, resulting in electrolytic corrosion. This can generally be circumvented by insulating the earth wires of the towers near pipelines. Though effective, this measure has cost implications for the utility and can, in the case of long parallelisms, present a safety hazard to live line workers and OPGW maintenance personnel if not carefully managed.

Prior to 2010, no local standard or guideline was available to deal with these issues, and no specific voltage (or current) limits were recommended or regulated. This led to either over- or under-design of mitigation measures, resulting in damaged pipelines, corroded power line towers and earth wires, and electrical shocks experienced by maintenance personnel on pipeline infrastructure.

To address this issue, a SABS working group was established during 2010 representing the local electricity supply, pipeline and cathodic protection industries, with the objective of developing a standard or guideline through the NRS mechanism. Due to the time scale involved in drafting SANS documents, Eskom’s Line Engineering Services proceeded to develop an in-house guideline, in consultation with the SABS working group, to attend to the immediate needs.

The first (2015) revision of this document became the de-facto guideline for addressing electrical interaction between Eskom’s power lines and metallic pipelines, however, over time, additional issues were identified, and with advances in research, some of the recommendations became outdated.

This second (2024) revision, again prepared in consultation with the previously established working group, addresses these issues, mainly covering the following:

- revised criteria for a.c.-induced pipeline corrosion based on the latest research,
- introduction of a risk-based analysis to establish the tolerable risk at co-locations,
- effect of utility-scale PV installations on nearby pipelines,
- review of power line steady state load limits and conductor types in use,
- review of the dielectric strength of pipe coatings,
- review of equipotential bonding methods inside and outside valve chambers,
- review of protective device specifications,
- protective measures for areas with a high risk of vandalism.

2. Supporting clauses

2.1 Scope

This Guideline addresses safety and interference issues arising from electrical coupling between a.c. or d.c. power lines and metallic pipelines. It is applicable when pipelines cross or share power line servitudes, or when pipelines and power lines are installed in adjacent or overlapping servitudes.

Capacitive, inductive and conductive coupling modes are considered during normal load and fault conditions, for overhead lines or underground cables coupling with pipelines above or below ground, when the line voltage exceeds 40 kV r.m.s. on overhead lines[1)], or 10 kV r.m.s. on cables.

This Guideline provides interference limits, guidance on the calculation and measurement of coupling levels, protection and mitigation methods, safe installation practices in power line servitudes as well as the co-ordination and management procedures required between the respective authorities.

Non-metallic pipelines (PVC, fibre-cement, concrete, ceramic etc.) are generally not subject to electrical coupling effects and are not considered in this Guideline, although the civil and mechanical considerations (e.g. excavation and building restrictions near tower structures, safe working procedures in power line servitudes, etc.) also apply.

[1)] *Note: In the case of close parallelisms exceeding 3 km in length in combination with pipe coatings of high resistivity or above-ground pipelines, the inductive coupling mode is also considered for overhead lines with line voltages in the 10 kV – 40 kV range.*

2.1.1 Purpose

Eskom's power lines and bulk pipelines often compete for the same land space (servitudes). In some cases, where the power lines already exist, a new pipeline can impact the existing power lines plus any additional power lines that are planned. In the opposite situation, where a pipeline exists, new power lines may have an impact on the pipeline.

This document is aimed at setting up the framework that describes how the impacts are calculated and dealt with in either of these situations.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions whenever a pipeline and power line interaction is identified (covering existing and planned future infrastructure).

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

[2] IEC 60050-161, International electrotechnical vocabulary. Chapter 161: Electromagnetic compatibility

[3] Electricity Regulation Act 4 of 2006

[4] Occupational Health and Safety Act No. 85 of 1993

[5] SANS 10280, Overhead Power Lines for conditions prevailing in South Africa, Part 1: Safety

[6] SANS 10142-1, The wiring of Premises, Part 1: Low voltage Installations

2.2.2 Informative

[7] 240-130615862, Earthing of Transmission Line Towers (previously TST-41-321)

[8] 240-103616534, Standard for the Approval of Work where Eskom's Rights may be Encroached Upon and/or Services/Assets placed at Risk

[9] 240-61227332, Co-use of Eskom Servitudes, Restriction Areas and Assets Guideline (previously DGL 34-363)

[10] 240-125383428, Building line restrictions, Servitude Widths, Line Separations and Clearances from power lines (previously DGL 34-600)

[11] SANS 50162:2010, Protection against corrosion by stray current from direct current systems

[12] SANS 61643-1:2006, Low-voltage surge protective devices, Part 1: Surge protective devices connected to low-voltage power distribution systems - Requirements and tests

[13] 240-147806256, Determination of conductor ratings in Eskom

[14] CIGRE 95 36.02: 1995, Guide on the influence of High Voltage AC Power Systems on Metallic Pipelines

[15] CIGRE 290 C4-2-02: 2006, AC Corrosion on Metallic Pipelines due to Interference from AC Power Lines – phenomenon, Modelling and Countermeasures

[16] ANSI/IEEE Std 80, IEEE Guide for Safety in AC Substation Grounding

[17] ANSI/IEEE Std 81, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System Part 1: Normal Measurements

[18] IEC Std. 60479-1: Effects of current on human beings and livestock, Part 1- General aspects

[19] SANS 10199:2004, The design and installation of earth electrodes

[20] NRS084-2:2007: Electricity Supply – Quality of Supply Part 2: Voltage characteristics, compatibility levels, limits and assessment methods

[21] CAN/CSA-C22.3 No. 6-M91: R2003, Principles and practices of electrical coordination between pipelines and electric supply lines

[22] AS/NZS 4853: 2011, Electrical hazards on metallic pipelines

[23] EN ISO 18086: 2020, Corrosion of metals and alloys - Determination of AC corrosion – Protection criteria (previously EN 15280)

[24] EN 50443: 2011, Effects of electromagnetic interference on pipelines caused by high voltage a.c. railway systems and/or high voltage a.c. power supply systems

[25] NACE SP0177: 2014, Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Cathodic Protection Systems

[26] NACE Internal Publication 35110: 2010: AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements

[27] Von Baeckmann W., Schwenk W. et al,1997, Handbook of Cathodic Corrosion Protection, 3rd Edition, Gulf Professional Publishing

[28] Sunde, E.D., 1949, Earth Conduction Effects in Transmission Systems, D. van Nostand Co., Inc.

[29] CEA Report 239 T817, 1994, Powerline Ground Fault Effects on Pipelines, Prepared by Powertech Labs Inc.

[30] ITU-T Directives, R2005, Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines, Volume II – Calculating induced voltages and currents in practical cases

[31] ITU-T Rec K68: 2006, Management of electromagnetic interference on telecommunication systems due to power systems

[32] Sealy-Fisher, V., Webb N., 1999, Cahora Basa Power Line Interference Study, Technical Bulletin No. 12, SAECC/4/1

[33] Brenna, A., Ormelesse, M. et al, AC Corrosion of Carbon Steel under Cathodic Protection Condition: Assessment, Criteria and Mechanism: A Review, Materials 2020.

[34] ISO 22426: 2020, Assessment of the effectiveness of cathodic protection based on coupon measurements

[35] CIGRE P8.06: 2017, Thomas C, Seasonal Variation of Soil Resistivity and the Correction Factor

[36] Demetriou, A. et al, Stray Current DC Corrosion Blind Spots Inherent to Large PV Systems Fault Detection Mechanisms: Elaboration of a Novel Concept, IEEE Trans. on Power Delivery 2015

[37] 240-86640998, Supervision of people in electrically hazardous locations

2.3 Definitions

2.3.1 General

For the purposes of this guideline, the terms, definitions and abbreviations given in IEC 60050-161 and the following apply:

Definition	Description
anode ground bed	an installation of conductors below the surface by which direct current is discharged into the earth in an impressed current cathodic protection system
appurtenance	that which is connected to a pipeline, e.g. a valve in a pipeline
auto-reclosure	action of the power line protection whereby the line is automatically re-energised one or more times after tripping
bond	a low impedance connection designed to maintain a common electric potential
coating stress	the difference in voltage potential between the pipeline wall and the surrounding soil at a given location
counterpoise	a conductor or system of conductors below ground, connected to the footings of power line towers
d.c. decoupling device	a device used in electrical circuits that allows the flow of a.c. in both directions and prevents or substantially inhibits the flow of d.c.
d.c. potential shift	a potential developed between a metallic structure and the surrounding earth because of stray d.c. currents in the earth, which can result in electrolytic corrosion of the metallic structure
dielectric breakdown potential	a voltage potential in excess of the rated voltage that causes the destruction of the coating or other insulating material
discharge current	current that will flow if the conductor with induced voltage is connected to the earth via a zero-impedance bond
dead front	a type of construction in which the energized components are recessed or covered to preclude the possibility of accidental contact
earth potential rise	the product of an earth electrode impedance, referenced to remote earth, and the current that flows through that electrode impedance
earth resistivity	measure of the electrical resistance of a unit volume of soil NOTE The commonly used unit is the ohm.meter, [Ω.m] which refers to the impedance measured between opposite faces of a cubic meter of soil.
galvanic corrosion cell	corrosion caused by dissimilar metals in an electrolyte

Definition	Description
gradient control wire	one or two ribbons installed adjacent to and connected to a pipeline to reduce the pipeline coating stress
gradient control mat	a system of bare conductors or ribbon on or below the earth's surface, so designed as to provide an area of equal potential within the range of step distances
impressed current cathodic protection	a system whereby the cathodic protection current is applied using a d.c. rectifier, connected between the protected item and an anode ground bed
remote earth	a location on earth that is far enough from the affecting structure that the soil potential gradients associated with the currents entering the earth from the affecting structure are insignificant
residual current (or zero sequence current)	Electrical current, that is equal to the phasor sum of the phase currents, which returns through the earthing system of the power network NOTE When balanced current conditions exist, the residual current equals zero
ribbon	a bare zinc or magnesium profiled conductor, specifically designed for gradient control
right (or right-of-way)	means the right to traverse or occupy land and may include services, surface right permits, way leaves, exercised options, licences and permissions to occupy
sacrificial anode	an anode that is attached to a metal object subject to electrolysis and is decomposed instead of the object
screening factor	a factor smaller than unity, by which an inducing quantity (current or voltage) may be multiplied to represent the reducing effect of a screening conductor
servitude	a right registered at the Registry of Deeds against the property title deed, binding against all the successors in title.
step voltage	the voltage difference between two points on the earth's surface separated by a distance of a pace, which is assumed to be 1 m, in the direction of the maximum voltage gradient
switching surge	the transient wave in an electrical system that results from the sudden change of current flow caused by the opening or closing of a circuit breaker
touch voltage	the voltage difference between a metal structure and a person in contact with the earth's surface or another metal structure
test post	a location at ground elevation above the pipeline where leads connected to the pipeline and/or pipeline coupons are accessible for the measurement of the voltage of the pipeline and/or the corrosion current
voltage limiting device	a protective device that normally presents a high impedance in an electrical circuit but presents a low impedance when its rated clamping or spark-over voltage is exceeded
zone of influence	area adjacent to a power line or installation in which inductive, capacitive or conductive coupling or a combination of them can produce harmful effects on a pipeline installation

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
ACSR	Aluminium Composite, Steel Reinforced
ARC	Auto reclose
CP	Cathodic Protection
CVES	Continuous Vertical Electrical Sounding
DCVG	Direct Current Voltage Gradient
DSR	Deep Soil Resistivity
Dx	Distribution (MV and HV)
EHV	Extra High Voltage (>132kV)
emf	electromotive force
EPR	Earth Potential Rise
ESI	Electricity Supply Industry
ESA	Electricity Supply Authority
ESO	Electrical Safety Officer
GIS	Geographical Information System
GMR	General Machinery Regulation
HV	High Voltage (44kV to 132kV)
ICCP	Impressed Current Cathodic Protection
LV	Low Voltage (<1kV)
MV	Medium Voltage (1kV to 33kV)
NEDCSA	National Electricity Distribution Company of South Africa SOC Ltd
NEC/R	neutral earthing compensator/resistor
NTCSA	National Transmission Company South Africa SOC Ltd
OHS	Occupational Health and Safety
OPGW	optical ground wire
ORHVS	Eskom operating regulations for high-voltage systems
PILC	paper insulated, lead covered
PO	Pipeline Operator
PSS/E	power systems software simulator for engineering
PV	photovoltaic
SCOT	Steering Committee of Technology
SPD	surge protection device
Tx	Transmission (EHV)
TxSIS	Eskom Tx division’s spatial information system
VLD	Voltage limiting device
XLPE	cross-linked polyethylene
ZOI	Zone of influence

2.5 Roles and responsibilities

The Line Engineering Services (LES) department within Eskom's Transmission Division (soon to be NTCSA, National Transmission Company South Africa SOC Ltd) is the main originator of Tx line designs, through application of Eskom guidelines and standards developed and maintained under SCOT. Transmission self-build projects, where the new line sections are designed and constructed by private entities (in liaison with the Review Committee within LES), are subject to the same requirements.

Throughout Eskom Distribution (soon to be NEDCSA, National Electricity Distribution Company South Africa SOC Ltd) offices countrywide, there are also designers doing Dx line designs and development work, sometimes engaging private design consultants who would then submit new line designs through Dx Design Review Committees.

Regardless of whether power lines are designed and developed by Tx / NTCSA or Dx / NEDCSA offices or by private consultants, line designs must always take cognisance of pipeline(s) and servitudes that are on record. This Guideline must be applied whenever new or upgraded power lines are expected to approach or cross any existing or planned pipelines.

In addition, all applications received from pipeline operators for the co-use of Eskom's servitudes must be processed according to this Guideline, following the procedure set out in 3.2.2 and annex C. Land development departments in Tx / NTCSA and Dx / NEDCSA should engage their respective engineering services departments to establish if the proposed co-use of the servitude is technically feasible and if mitigation measures are required to ensure safe operation, prior to the issuance of co-use approvals.

2.6 Process for monitoring

The electrical working group in the Overhead Lines study committee of SCOT (within Tx / NTCSA) will monitor this document and others that are related to power line design and operation. It will take place either under a working group or a care group, depending on the needs identified. The SCOT focus is both on technical issues as well as operational issues that may require modifications or updates. Advances in pipe coatings and CP systems need to be monitored continuously to ensure that the technical impacts remain acceptable.

Through the formulation of this document, with inputs and interaction by the pipeline operators, Eskom has set the benchmark for what would be required when power lines and pipelines interact.

The pipeline industry of South Africa as well as Eskom is keen to support the continued development of this document into a national standard through the NRS mechanism.

2.7 Related/supporting documents

Not applicable.

3. The Electrical Coordination of Pipelines and Power Lines

3.1 Statutory and Utility Requirements

3.1.1 Applicable legislation

When a new electrical transmission or distribution scheme or extension to a scheme is considered in the vicinity of an existing pipeline, or when a new pipeline or extension of an existing pipeline is considered in the vicinity of an electricity transmission or distribution scheme, the following legislation is applicable in South Africa:

a) the OHS Act, 1993 (Act No. 85 of 1993) and its accompanying regulations, notably the Electrical Machinery Regulations, 2011 (GNR.250 published in Government Gazette 34154 of 25 March 2011),

b) the Electricity Regulation Act 4 of 2006.

The OHS Act also has specific regulations for gas and petroleum pipelines related to the dangers posed by the transported medium (the Major Hazard Installation Regulations, section 43 of Act No 85), which are outside the scope of this document.

3.1.2 Relevant statutory requirements

Relevant requirements, in the context of this guideline, from the legislation listed in 3.1.1 stipulate the following:

a) In terms of section 8(1) of the OHS Act, POs and ESAs are obliged to provide and maintain safe working environments which include working environments where pipelines or works are under or in the vicinity of power lines.

b) In terms of the Electricity Regulation Act (Section 25), in the event of civil proceedings arising from damage or injury caused by induction, leakage or any other means of unwanted transmission of electricity, the ESA will be presumed to have been negligent unless it can prove otherwise.

c) The Electrical Machinery Regulations obliges POs and ESAs to conform to the safety clearances as set out in Regulation 15 in respect of overhead power lines, and it is necessary to define all electrical works and pipeline facilities to which safety clearances may be applicable and to agree on the safety clearances that must apply in each case.

3.1.3 Utility requirements for pipeline installations in Eskom's servitudes

The minimum requirements for Eskom’s servitudes are given in 240-103616534 [8] and 240-61227332 [9] and for Dx lines and in 240-125383428 [10] for both Tx and Dx lines, in addition to further requirements listed here. The specific requirements in the context of this document are:

3.1.3.1 Common requirements (Dx and Tx servitudes)

a) No work may commence unless Eskom has received the applicant’s written acceptance of the conditions specified in the letter of consent.

b) The applicant or his / her contractor on site must at all times be in possession of the letter of consent. Should the site agent or contractor on site not be able to produce the required approval on inspection, all site activities will be stopped.

c) Eskom's rights and duties in the servitude shall be accepted as always having prior right and shall not be obstructed or interfered with.

d) Eskom’s consent does not relieve the applicant from obtaining the necessary statutory, land owner or municipal approvals. Applicants are reminded that power line servitudes do not imply land ownership by Eskom.

e) Eskom shall always retain unobstructed access to and egress from its servitudes.

f) Pipelines shall not conflict with Eskom's future expansion plans in the servitude.

g) In general, parallel encroachments into the servitudes are limited to 2 (two) metres from the boundary of the servitude, to allow reasonable maintenance access to Eskom in the servitude.

h) Pipeline transitions from one side of the power line servitude to the other are not permitted without written approval.

i) The angle of all crossings should preferably be from 45 degrees to 90 degrees.

j) Venting and blow off valves on gas or petroleum pipelines shall be outside the power line servitude and be vented away from potential ignition sources.

k) Pipeline markers shall be installed at 10 m intervals (or as otherwise specified by Eskom) to indicate the location of underground pipelines. Markers shall indicate the owner of the pipeline and be concrete cast and resistant to vandalism.

l) Sufficient cover or pipe jacking shall be provided at servitude roads to prevent breakage by Eskom's vehicles and heavy equipment.

m) In case of a proposed above-ground pipeline, a bridge shall be provided to allow permanent Eskom access to the servitude. This bridge, if of conductive material, shall be earthed, but the earthing shall not be onto Eskom structures or within five metres of Eskom's own earthing.

n) At a pipeline crossing, corrosion-free sleeves must be installed at least 600 mm below undisturbed ground level to provide for future installation of Eskom cables. [The number and diameter shall be determined by the internal assessor]

o) The construction of new temporary or permanent metallic fences in power line servitudes can be extremely hazardous and is prohibited without written approval.

p) The use of explosives of any type within 500 metres of Eskom's services is prohibited without written approval.

q) The pipeline voltages resulting from electrical coupling during normal and fault conditions on the power line(s) shall not exceed the respective values indicated in 3.3.3 and 3.3.4.

r) The stray d.c. voltages near power line structures resulting from ICCP systems shall not exceed the values indicated in 3.3.8.

s) Test posts shall use dead front construction in accordance with NACE RP0177.

t) It is required of applicants to familiarize themselves with all safety hazards related to Electrical plant. Safe working procedures shall be applied during construction (see 3.8).

u) The clearances between Eskom's live electrical equipment and the proposed construction work shall be observed as stipulated by Regulation 15 of the Electrical Machinery Regulations of the Occupational Health and Safety Act, 1993 (Act 85 of 1993) (see 3.8.2, table 16).

v) No mechanical equipment, including mechanical excavators or high lifting machinery, shall be used in the vicinity of Eskom's apparatus and/or services, without prior written permission having been granted by Eskom. If such permission is granted the applicant must give at least seven working days prior notice of the commencement of work. This allows time for arrangements to be made for supervision and/or precautionary instructions to be issued. The internal assessor must provide the applicant with the details of an Eskom person to be contacted in this regard.

w) Changes in ground level may not infringe statutory ground to conductor clearances or statutory visibility clearances. After any changes in ground level, the surface shall be rehabilitated and stabilised to prevent erosion. The measures taken shall be to Eskom's requirements.

x) Electrical installations on the pipeline for example the cathodic protection system, protection devices and electrical wiring shall comply with the applicable provisions in SANS 10142 and inspected and certified by a qualified installation electrician (or master installation electrician in case of hazardous locations).

y) Eskom shall not be liable for the death of or injury to any person or for the loss of or damage to any property, whether resulting from the encroachment or from the use of the servitude area by the applicant, his/her agent, contractors, employees, successors in title, and assignees.

z) The PO shall indemnify Eskom in writing against loss, claims or damages including claims pertaining to consequential damages by third parties, whether resulting from interruption of service or interference with Eskom's services or apparatus or otherwise. Eskom shall not be held responsible for damage to the applicant's equipment.

aa) The PO's construction manager shall report any damage to Eskom's property, private property or public facilities, and the PO agrees to pay all expenses incurred in connection with the repair of such damages.

3.1.3.2 Further requirements for Tx servitudes

a) No excavations are permitted within 20 m of above-ground power line structures, as measured from the nearest tower leg, pole mast, guy anchor or other attachment. Exceptions may be permitted, subject to a case-by-case evaluation of the foundation and the soil conditions.

b) No above ground or semi-buried buildings are permitted within the following distances of a Tx power line, measured from the centreline of the power line, as a function of the voltage level:

i.	220 kV - 275 kV (delta):	18 m
ii.	220 kV - 275 kV (horizontal):	23.5 m
iii.	400 kV (self-supporting):	23.5 m
iv.	400 kV (stayed)	27.5 m
v.	765 kV	40 m

3.1.3.3 Further requirements for Dx servitudes

a) No excavations are permitted within 6 m of above-ground power line structures, as measured from the nearest tower leg, pole mast, guy anchor or other attachment. Exceptions may be permitted, subject to a case-by-case evaluation of the foundation and the soil conditions. In such cases, or where there is a risk of a ruptured pipe eroding a tower foundation, the pipe section is to be placed in concrete.

b) No above ground or semi-buried buildings are permitted within the following distances of a Dx power line, measured from the centreline of the power line, as a function of the voltage level:

i.	all voltages below 22 kV:	9 m
ii.	22 kV:	9 m
iii.	33 kV – 88 kV:	11 m
iv.	132 kV:	18 m

3.2 Co-ordination and Management Procedure

3.2.1 Co-ordination

Good co-operation between Eskom and the POs is essential to ensure that all the co-ordination requirements are met. Both parties must ensure that adequate specialist skills are available to them, to enable professional assessment of the methods and measures used to prevent conditions which may be dangerous to employees concerned or to the public, or which may damage or degrade the pipeline or power line works.

Co-ordination and service meetings between the specialists of the POs and Eskom should complement the formal meeting mentioned in 3.2.2 o), particularly in the case of long or complex exposures.

When the servitude under consideration contains both Dx and Tx power lines, the co-operation *must extend to both Eskom's Dx and Tx departments*. It is emphasised that since the respective Land & Rights issues are under the management of separate offices, any approval granted by Eskom Dx does not automatically imply Eskom Tx approval, or vice versa.

Further liaison between the specialists of the respective parties is recommended through the forum of the SAECC. The preferred arrangement is that an SAECC working group is established with the responsibility of sharing information and developing skills in respect of electrical coupling between power lines and pipelines, including the training of safety officers.

3.2.2 Procedure for obtaining approval for new installations

When a new pipeline is planned that involves any construction in Eskom's servitudes, the steps required towards approval of the right of way are as listed below. A corresponding flow chart is provided in Annex C.

For applications involving both Tx and Dx lines, *two separate applications must be processed*, as detailed hereunder.

a) the PO's right of way application (annex A of 240-61227332 [9]) along with the pipeline design details according to checklist A.1 of Annex A, is completed and submitted to Eskom's regional office for attention of Land and Rights, at least six months prior to planned commencement of the project,

b) the application is checked for completeness, registered on the system (Investigations_ logbook.xls) and assigned a Senior Advisor: Investigations and Audit (Tx) or to an Internal Assessor (Dx), according to the procedures described in 240-103616534 [8] and 240-61227332 [9],

c) the Senior Advisor or Internal Assessor examines the application and identifies the affected Tx and Dx power lines or cables on TxSIS GIS, and captures this information using the template A.2 in Annex A,

d) the Senior Advisor or Internal Assessor query the Manager: Land Management and Grid Planning if any future power lines or cables will be affected by the application in a 20-year window, and likewise captures this information,

e) the Senior Advisor or Internal Assessor prepares maps or .kmz or .dxf files clearly indicating the routes of all the affected power lines or cables as well as other infrastructure in the area of interest,

f) the Senior Advisor or Internal Assessor updates TxSIS GIS with the pipeline ID and route and forwards this information to the SCOT committee (for attention: SCOT chairperson),

g) the Senior Advisor or Internal Assessor next forwards the application with the power line route maps to Eskom's Engineering Services, who performs an assessment of the ZOI (Zone of Influence) and risk level, using the information obtained in steps a) - e) and following the methods discussed under 3.4,

h) if the exposure or crossing is benign, the application is returned to the Senior Advisor or Internal Assessor for further processing and subsequent approval or otherwise according to the procedure described in [8] and [9], but noting that if any construction work is to be done in a power line servitude, the safe working procedures of 3.8 are applicable,

i) if the pipeline falls within the ZOI of inductive and/or conductive coupling and the corresponding risk level (see 3.4.3) is unacceptable, or if the power line or any substations fall inside the ZOI of the pipeline's CP system, the exposure is regarded as possibly hazardous and a detailed coupling study is required for the respective coupling mode(s),

j) the design details of the relevant power lines or cables are then obtained from Lines Engineering and Grid Planning, taking network expansion for a 20-year period into account, using the checklist A.3 in Annex A,

k) Eskom's Engineering Services performs a PSS/E or similar analysis to calculate the network impedances and fault current levels for the power lines or cables in question, using the checklist A.4 in Annex A, using case files 20 years ahead,

l) the list of possibly hazardous coupling modes and all the relevant power system data (from checklists A.2, A.3 and A.4) is forwarded to the PO,

m) the PO designs the a.c. mitigation based on this data, according to the methods indicated in 3.7 and elsewhere in this guideline, and submits a proposal to the Senior Advisor who submits same to Eskom's Engineering Services,

n) if necessary, Eskom's Engineering Services initiates and proceeds with a project to assess the suitability of the a.c. mitigation measures proposed by the PO,

o) a co-ordination meeting is held between Eskom's Engineering Services and the PO to reach agreement on designs that will ensure that the coupling limits will not be exceeded and to discuss the necessary clearances and safety procedures to be observed,

p) Eskom's Engineering Services initiates a project (in Eskom Construction Department) to isolate the power line's earth wires as may be required in terms of 240-130615862 [7] or as indicated by the conductive coupling analysis,

q) the application is returned to the Senior Advisor for further processing and approval subject to the agreed design,

r) before construction starts, the PO appoints an Electrical Safety Officer (ESO), who is to be responsible for maintaining safe working conditions in the servitude and adjacent to the servitude for the duration of the works (see 3.8),

s) during construction, the ESO maintains contact with Eskom and permits inspections by Eskom representatives to ensure that all conditions are met, and the required clearances are adhered to,

t) the ESO keeps a written record of all voltage measurements, safety-related incidents and accidents during construction, exposed underground infrastructure such as counterpoises or cables and any damage to Eskom's power line structures, and submits this information to Eskom,

u) upon completion of the pipeline works and surface restoration, an Eskom representative performs an inspection of all a.c. mitigation measures, the pipeline markers, any damage to power line structures and the quality of the surface restoration (see 3.9 and inspection sheet in Annex D),

v) if so agreed upon by the parties, measurements are performed at this stage to determine if the d.c. potential shift at selected pylons or earth mats, resulting from switching the CP system on and off, is within the required limits,

w) provided that the outcome of steps u) and v) is positive, the final approval for the commissioning of the installation is granted (see 3.9).

When a new power line or installation is planned in an existing pipeline servitude, essentially the same procedure is followed; in this case initiated by Eskom, and subsequently inspected and approved by the PO.

3.2.3 Cost of mitigation, protection and maintenance measures

In the case of new works, the cost of the agreed upon measures shall be borne by the party initiating the new installation. This includes the cost of any modification required to the existing works belonging to the owner of the servitude. In the case of a pipeline application in an existing power line servitude, this could include, for example, the cost of isolating the power line's earth wires. In the case of a new power line influencing an existing pipeline, this would include the cost of all the a.c. mitigation measures required.

The holder of the earlier servitude shall further be entitled to recuperate from the applicant the cost of the assessment described in 3.4, the cost of the modelling exercise described in 3.6, the cost of inspections and if damage occurred, the cost of any repairs to the existing works.

In the case of induction problems arising on existing installations, the cost shall be borne by the party on whose installation the protection or mitigation measures are implemented.

In the case of a benign co-location becoming hazardous due to a power line upgrade or an increase in the level of cathodic protection used on the pipeline, the cost shall be borne by the party who was granted permission for co-use of the earlier servitude.

In the case of there being no registered servitude owner yet at the time that the co-location is planned, each party shall be responsible for the cost of the measures on their own equipment, whilst the cost of the assessment and modelling exercise shall be equally shared.

In all cases, each party is responsible for the cost of maintaining the integrity of their own equipment including attachments, insulation and earthing.

3.3 Coupling Limits

3.3.1 Origin of safety limits

Safe limits of step and touch voltages are based on the maximum body current that can be endured by a person without affecting muscular control or causing ventricular fibrillation. The standards IEEE 80 and IEC 60479-1 provide safety criteria based on the fibrillation current derived from empirical studies.

The safety limits used here for fault conditions are adopted from the IEC standard, which is based on more recent research. The fibrillation current curve C1 is used, representing 95% of the population (see Fig 20 in IEC 60479-1).

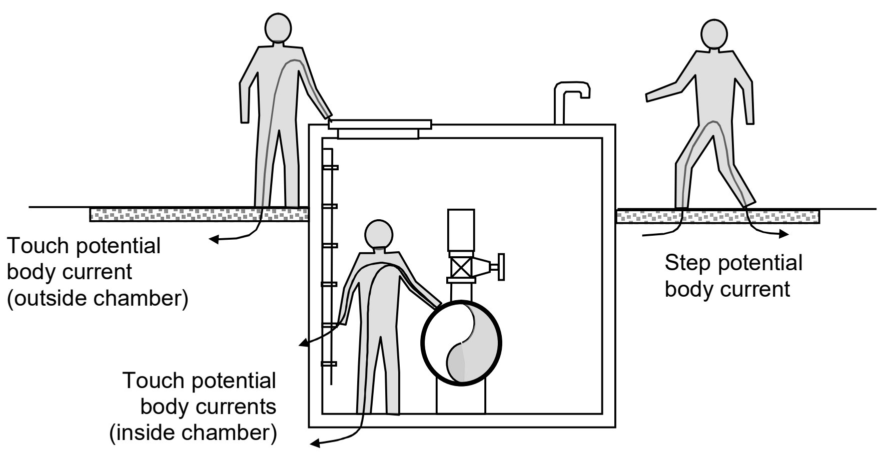
For pipeline sections exposed to the general public, the worst-case condition considered is where both hands are in contact with the pipeline and both feet in contact with the earth. No reduction factor for footwear is applied, as some pipelines may be accessible to bare-footed children, for example.

For pipeline sections accessible only by authorised personnel, the worst condition considered is likewise where both hands are in contact with the pipeline and both feet with the earth, but footwear is accounted for with a conservative resistance of 1000 ohm.

The safety limits for steady state conditions are based on a 10 mA r.m.s. body current, which is the maximum safe let-go current for adult men. For pipelines or sections of the pipeline exposed to the public including children, this level is reduced to 5 mA r.m.s. The hand-to-hand or hand-to-foot resistance is considered to be equal to or higher than 1 500 ohm, a reasonably safe assumption when touch voltages remain within the limits required (see Table 1, IEC 60479-1).

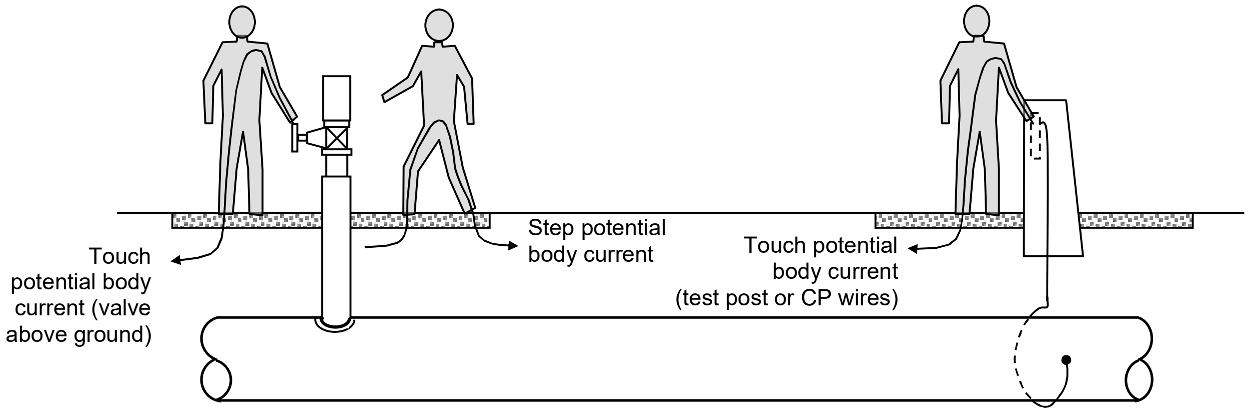
3.3.2 Contact scenarios

Some typical contact scenarios with an energised pipeline and the resultant body current paths are depicted in Fig1 (a)-(c).

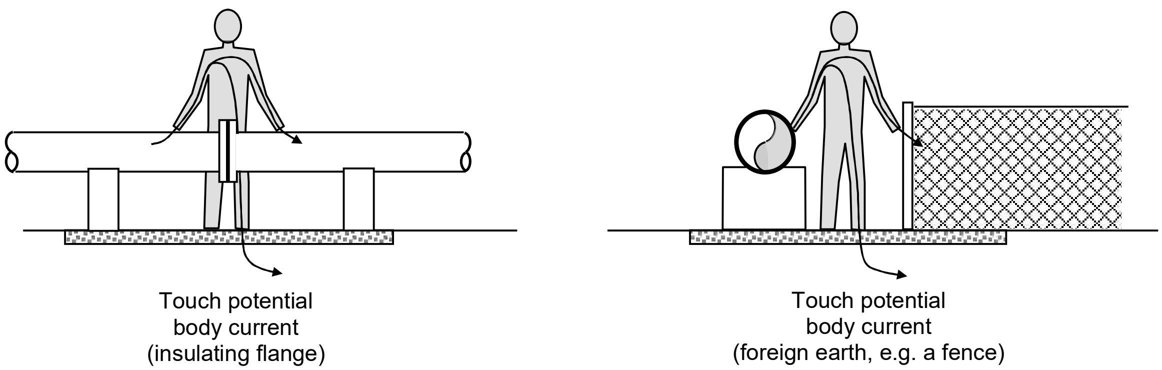


(a) At partially buried valve chambers

Figure 1: Typical contact scenarios with an energised pipeline and body currents due to step and touch potentials



(b) At above-ground appurtenances



(c) Across insulating flanges and to separate earths

Figure 1 (cont.): Typical contact scenarios with an energised pipeline and body currents due to step and touch potentials

Step and touch potentials can result from the voltage gradient around the chamber (see Fig 1 (a)) or the above-ground appurtenance (see Fig 1 (b)).

Inside valve chambers, direct contact with the pipeline is possible, and the current path can be hand-to-foot, through the chamber floor, or hand-to-hand, through a metallic component either bolted into the concrete or earthed to the re-bar (such as a ladder, see Fig 1 (a)).

Outside valve chambers, indirect touch potentials can occur through contact with external metallic components that could be at (or near) pipe potential through the reinforced concrete (e.g. a lid; see Fig 1(a)). This specific contact scenario may be disregarded when such metallic components are inaccessible to a person standing on the ground next to the chamber, or when the pipe is intentionally insulated from the concrete structure. In this case, only the step potential needs to be considered.

With pipelines installed on plinths above ground, direct touch potentials are possible to local earths, to foreign earths or across insulating flanges (see Fig 1 (c)).

3.3.3 Limits relating to danger during fault conditions

In the event of an earth fault on the power line(s), the touch and step voltages with respect to local earth at any accessible section of the pipeline shall not exceed the values given in Table 1, for public and occupational exposure respectively.

For most pipelines the occupational exposure limits will be applicable. The public exposure limits are only applicable for above - ground pipelines or appurtenances that are not protected from public access.

Table 1: Limiting values for induced pipeline touch and step voltage during faults

Exposure	Fault duration[1)], t [s]	Maximum touch (T) and step (S) voltages for different surface layers: [V r.m.s.]		
		Natural soil or concrete slab[2)]	**15-20 cm crushed stone layer[2)]**	**15-20 cm asphalt layer[2)]**
General public	t ≤ 0,1	170 (T) 220 (S)	570 (T) 1 800 (S)	4 300 (T) > 5 000 (S)
	0,1 < t ≤ 0,2	160 (T) 200 (S)	510 (T) 1 600 (S)	3 800 (T) > 5 000 (S)
	0,2 < t ≤ 0,5	60 (T) 70 (S)	170 (T) 510 (S)	1 200 (T) 4 600 (S)
	0,5 < t ≤ 1,0	34 (T) 40 (S)	90 (T) 260 (S)	600 (T) 2 300 (S)
	1,0 < t ≤ 20	26 (T) 32 (S)	70 (T) 200 (S)	450 (T) 1 700 (S)
Authorised personnel	t ≤ 0,1	340 (T) 900 (S)	820 (T) 2 600 (S)	4 500 (T) > 5 000 (S)
	0,1 < t ≤ 0,2	300 (T) 800 (S)	730 (T) 2 300 (S)	4 000 (T) > 5 000 (S)
	0,2 < t ≤ 0,5	105 (T) 260 (S)	240 (T) 720 (S)	1 250 (T) 4 800 (S)
	0,5 < t ≤ 1,0	60 (T) 135 (S)	130 (T) 370 (S)	640 (T) 2 400 (S)
	1,0 < t ≤ 20	45 (T) 110 (S)	95 (T) 270 (S)	460 (T) 1 800 (S)

Notes:

1) Use the cumulative fault duration of the maximum number of reclosures.

2) Assumed resistivity of natural soil or concrete slab: 30 ohm.m, crushed stone: 1000 ohm.m, asphalt: 10 000 ohm.m; all under wet conditions, ref. IEEE 80.

The benefit of a protective surface layer is evident from Table 1. Asphalt in particular exhibits a very high resistivity. Concrete slab (and soilcrete, i.e. backfill mixed with cement) on the other hand, is a very poor insulator, due do the hygroscopic nature of cement.

The fault duration on Eskom lines of usual construction is given in Table 2. In accordance with IEEE 80, the cumulative fault duration should be applied taking account of the auto-reclosures.

Table 2: Typical fault duration on Eskom power lines

Voltage level	Maximum fault duration [s]	Total number of successive trips [1)]	Cumulative fault duration [s]	Backup protection duration [2)] [s]
11 kV – 33 kV [3)]	4.0	5	20	20
44 kV – 132 kV	with teleprotection: 0.1 with stepped-distance protection [4)]: 0.5	2	with teleprotection: 0.2 with stepped-distance protection [4)]: 0.5	0.8[5)]
220 kV – 765 kV	0.1	2	0.2	0.8[5)]

Notes:

1) Trips in quick succession with auto-reclose, excluding controlled closure after ARC lock-out
2) Apply backup protection times only for pipelines continuously and frequently exposed to the general public, e.g. above-ground pipelines in public walkways
3) Eskom's MV circuits are earthed with NEC/Rs which limit the earth fault current to 360 A
4) This value applies only to the last 20% of the line, which uses Zone 2 protection and does not auto-reclose. Between 20% and 80% of the line, the fault will be cleared within 0.1 sec by Zone 1 from both ends
5) This applies to Zone 3 protection. High impedance faults (Zfault > 20 ohm) may take 1 sec or longer to clear, but have a reduced fault current

3.3.4 Limits relating to danger during steady state conditions

During worst case conditions on the power line(s), the touch voltage of the pipeline and its appurtenances shall not exceed [25]:

a) 15 V r.m.s. at pipeline sections exposed only to authorised personnel,

b) 7.5 V r.m.s. at pipeline sections exposed to the general public.

Worst case conditions shall take into consideration the emergency load current, the phase current unbalance, effects of multiple circuits and planned expansion or upgrade of the power network.

For most pipelines the 15 V r.m.s. limit will be applicable. The 7.5 V r.m.s. limit is only applicable for above - ground pipelines or appurtenances that are not protected from public access.

The locations on the pipeline where the voltage peaks will most likely occur are discussed in 3.6.9.

3.3.5 Limits relating to damage of pipeline coatings and insulating flanges

The permissible pipeline coating stress voltage is determined not as much by the dielectric strength of the coating or field joint material (which can be several kV or even tens of kV), as by the possible damage or disbondment that can occur due to arcing or glow discharges at gaps, cuts, cracks or pinholes that can be present on most coating types.

From [24] the recommended limits applicable during fault conditions (see 3.6.3.2) are:

a) 2000 V r.m.s. coating stress at any point on the pipeline,

b) 2000 V r.m.s. across insulating flanges.

Values greater than 2000 V r.m.s. may be accepted if the PO is confident that the coating is able to withstand such values and that damage at imperfections would be minor.

3.3.6 Limits relating to damage of cathodic protection equipment

The full induced a.c. voltage (i.e. without any localised mitigation) will appear across the CP rectifier during an earth fault. With proper design, this voltage will not exceed the maximum permissible coating stress.

The CP rectifier must hence be capable of withstanding the maximum coating stress voltage (see 3.3.5) for the duration of a fault cleared by the backup protection system (see Table 2).

The full induced steady state a.c. voltage will also appear across the CP rectifier and can be converted to a d.c. voltage, which can increase the ground bed d.c. current. The resultant increase in anode ground bed consumption needs to be considered during the ground bed design.

The CP equipment will further be vulnerable to lightning and switching surges through its power supply, in addition to possible transients from nearby d.c. traction systems. For this reason, the transformer and rectifier are equipped with SPDs, typically rated as follows:

- Lightning current rating 8/20 µsec 40 kA
- Lightning impulse clamping voltage (min) 500 V
- Response time 25 ns

Where surge levels are expected to exceed this rating, special precautions are required.

3.3.7 Limits relating to a.c. induced pipeline corrosion

The induced voltage ($V_{a.c.}$) and current density ($J_{a.c.}$) limits to prevent possible a.c. induced corrosion damage at pipeline coating defects must be decided by the PO and is not enforceable by the ESA. The information provided here is for guidance only.

Whilst the study of this phenomenon is ongoing [15, 23, 26, 33], there is clear evidence that for modern coatings, a.c. induced corrosion is possible at voltage levels well below the safety limits of 3.3.4, and moreover that the CP current density plays a critical role in a.c. corrosion susceptibility.

Specifically, CP overprotection (defect current density $J_{d.c.}$ greater than 1 A/m^2, or pipe-to-soil potential E_{on} more negative than -1.2 Vcse) was identified as one of the greatest risk factors in the presence of a.c. interference. Thus, rather than reducing it, high CP levels can increase the a.c. corrosion rate. It was also found that the corrosion rate is related to the ratio between the a.c. and d.c. current densities, $J_{a.c.}$ and $J_{d.c.}$ These effects have been taken into account in the latest ISO standard, EN ISO 18086:2020 [23].

Provided the minimum d.c. current density requirements of SANS ISO 15589-1 have been met and the pipeline's average a.c. voltage (as measured over a representative period, e.g. 24 h) does not exceed 15 V r.m.s., EN ISO 18086:2020 recommends *any one of* the following criteria to prevent a.c. induced corrosion:

a) maintain $J_{a.c.} \leq 30$ A/m^2 r.m.s., or

b) allow $J_{a.c.} > 30$ A/m^2, but maintain $J_{d.c.} < 1$ A/m^2, or

c) maintain the ratio $J_{a.c.} / J_{d.c.} < 5$,

where current densities $J_{a.c.}$ and $J_{d.c.}$ are *averages* on the surface of a 1 cm^2 coupon or probe (considered to be the critical defect size), as measured over a representative period (e.g. 24 h).

Criterion b) is generally the optimum solution as it avoids the risk of coating disbondment due to overprotection and requires the least a.c. mitigation, however it may require more frequent TRUs with lower current ratings to implement. E_{on} values must remain in the range -0.85 Vcse to -1.2 Vcse.

Criteria a) or c) may be applied in overprotection conditions, which are sometimes unavoidable in the vicinity of ground bed anodes or in conditions of low soil resistivity or significant d.c. interference (e.g. from d.c. railways). Criterion c) can require very high d.c. current densities and is often not ideal, leaving criterion a) as the more practical solution for these conditions.

From an empirical relationship between the voltage and the current density on a round 1 cm^2 defect [33], the average pipeline voltage corresponding to criterion a) is given by Eqn (1):

$$V_{a.c.} \leq 0.13 \cdot \rho \qquad \text{[V r.m.s.]} \qquad (1)$$

where ρ is the soil resistivity at pipe depth [ohm.m]

Eqn (1) may be applied in the design of the a.c. mitigation in regions where overprotection can occur. Variations in ρ should accounted for by measurements at frequent intervals and allowing for seasonal changes (see 3.5.3).

The resulting value(s) of $V_{a.c.}$ should not be exceeded with the average phase currents applied to the power line(s). If 24 h current measurements are not available, this average may be estimated as the design load of the line (normal load, not emergency load) multiplied by a factor of 0.8 to account for the load cycle.

Once the ICCP system becomes operational, d.c. current at coating defects can promote the formation of calcareous deposits or scaling, resulting in an increase in soil resistivity at the pipe-earth interface. If the soil contains a large ratio of alkaline cations to earth-alkaline ions, the deposits can adopt a chalk-like nature with the opposite effect, i.e. a reduction in soil resistivity. These deposits tend to be destabilized by a.c. current discharge; generally, this is accompanied by an increase in the a.c. current density. Furthermore, relatively high a.c. voltages on the pipeline (e.g. >10 V r.m.s) can, over time, shift the d.c. voltage E_{on} in the anodic direction, which can lead to rapid corrosion rates at coating defects [33].

With these complex interactions, the only way to confirm that $J_{a.c.}$ and $J_{d.c.}$ are maintained within the intended limits is by direct measurements with a.c. and d.c. probes or coupons on pipeline sections affected by a.c. induction.

Probes and coupons are further discussed in 3.7.1.7.

3.3.8 Limits relating to d.c. leakage from pipelines and anode ground beds

In terms of earthing standard 240-130615862 [7], all transmission line towers within 800 m of pipelines employing impressed current CP systems must have their earth wires isolated from the towers with suitable insulators, to prevent circulating d.c. currents.

Where it can be shown however by proper measurement and/or modelling that the d.c. potential shift limits indicated in a) or b) below are not exceeded, or if the towers are cathodically protected, this requirement may be waived, in consultation with Eskom.

a) Leakage from pipelines

With the pipeline at a negative potential, the adjacent soil will assume a negative potential through coating defects. Current can then be extracted from any earthed structure such as a power line tower, resulting in anodic interference (corrosion). To limit this effect, the maximum permissible d.c. potential shift of a steel structure with respect to the surrounding soil resulting from the CP system is (from Table 1, SANS 50162):

maximum positive d.c. potential shift (resulting from pipeline leakage): 200 mV

This limit is applicable for a steel structure in a concrete foundation and includes the IR - drop in the concrete surrounding the structure. It can be evaluated by toggling the CP system on and off whilst measuring the corresponding change in the structure's d.c. voltage, using a simple voltmeter and a reference electrode inserted into the soil next to the foundation. The maximum rated CP current should be applied to the pipeline during this test.

A 200 mV d.c. potential shift can manifest itself at the tower footing of a power line when the d.c. voltage gradient exceeds 400 mV over the length of a single power line span (see 3.4.2.4).

b) Leakage from anode ground beds to towers connected by earth wires

Anode ground beds produce a localised positive d.c. potential gradient in the adjacent soil, which injects current into nearby earthed structures, resulting in cathodic interference (protection).

Where this current exits the structure and re-enters the soil however, anodic interference (corrosion) occurs. When the power line's earth wires are directly connected to the towers, this return current is typically shared by several towers further away, before returning through the soil to the pipeline and back to the source (see 3.6.10 and fig 19).

The requirement in this case is that the return currents at these remote towers will not produce a positive d.c. potential shift more than 200 mV.

In view of this, post-installation measurements should be performed at all the towers where the current is expected to return to earth, to confirm that the 200 mV limit is met.

Such measurements are required whenever the d.c. potential shift at the current entry point exceeds 200 mV and should be made with the maximum rated current applied to the anode ground bed.

c) Leakage from anode ground beds to insulated towers

When anode ground beds are installed near power line towers (<500 m separation), the surface d.c. gradient across the individual legs or guy wire anchors can be large enough to cause corrosion even on towers with insulated earth wires. The applicable limit in this case is:

maximum positive d.c. potential shift (resulting from anode ground beds): 200 mV

This d.c. potential shift can manifest when the surface d.c. voltage gradient exceeds 400 mV over the distance between the legs or guy anchors. When this limit is exceeded, the tower must be protected with sacrificial anodes.

3.4 Assessment of the possible hazardous nature of an exposure

3.4.1 Data gathering

A significant amount of information concerning the pipeline and the power line(s) is required to enable a detailed study of the safety and corrosion aspects that results from the various electrical coupling mechanisms. The required information is covered in the checklists A.1 – A.4 of Annex A.

The step-by-step procedure for obtaining this information is provided in 3.2.2. Various sign-off areas are included in the checklists for each of the contributors to sign off before passing it on to the next step.

Only the information covered in checklists A.1 and A.2 of Annex A is required to determine the Zones of Influence (ZOIs) for the different coupling mechanisms, as outlined in 3.4.2. If no soil data is provided, a conservative value for deep soil resistivity of 1 000 ohm.m should be used for determining the ZOI for inductive coupling (see 3.4.2.1), or a surface resistivity of 5 000 ohm.m for determining the ZOIs for conductive coupling and d.c. coupling from the CP system (see 3.4.2.2, 3.4.2.4).

When the pipeline is found to be within one of the ZOIs of the power line, the corresponding information of checklists A.3 and A.4 is also required. Measurement of soil resistivity then becomes essential, as outlined in 3.5.

3.4.2 Establishing Zones of Influence

3.4.2.1 ZOI from overhead power lines and cables due to inductive coupling

This ZOI is determined by the distance between the centre of the power line and a parallel pipeline beyond which, the voltage developed on the pipeline cannot exceed a given limit. It is a function of the soil resistivity, the length of the exposure, the earth fault current level, the power system screening factors, the fault duration and the corresponding voltage limit.

For this calculation, the pipeline is assumed to be completely insulated, with no leakage through its coating, and with no earthing or mitigation measures applied.

The zone width a_i (applicable on both sides of the power line, see Fig 2) may be established for a specific situation from the equation:

$$a_i = 110 \cdot \sqrt{\frac{\rho}{e^{v/L_p} - 1}} \quad [m] \qquad (2)$$

where:

- ρ is the soil resistivity (see 3.4.1), [ohm.m],
- L_p is the length of the exposure, projected onto the power line (see Fig 3), [km],

and $v = \frac{64 \cdot V_{max}}{k_u \cdot k_p \cdot I_f}$ is a parameter calculated from the following values:

- V_{max}, the induced voltage limit for an earth fault, from Table 1, [V r.m.s.],
- k_u, the screening factor due to urban infrastructure, from ITU-T K.68 (see Table 3),
- k_p, the screening factor due the earth wires or the power cable sheath (see Table 3),
- I_f, the maximum phase-to-earth fault current level, [A r.m.s.].

Conversely, the maximum length L_p of an exposure with an average separation a_i is given by the equation:

$$L_p = \frac{v}{\ln\left(\frac{12100 \cdot \rho}{a_i^2} + 1\right)} \quad [km] \qquad (3)$$

For pipelines crossing power lines at right angles, L_p = 0 and no inductive coupling occurs. For crossings at angles greater than 60˚, inductive coupling remains very small and can be disregarded, provided the pipeline does not change direction towards the power line.

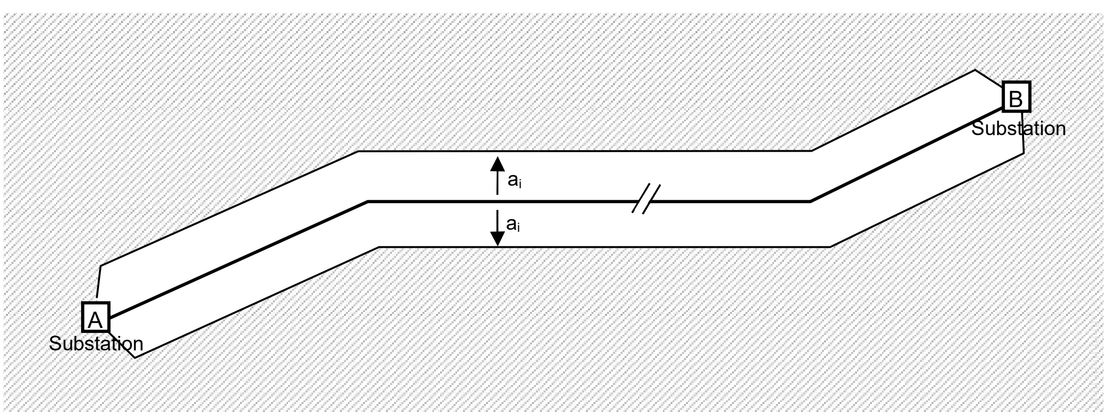


Figure 2: Zone of influence for inductive coupling

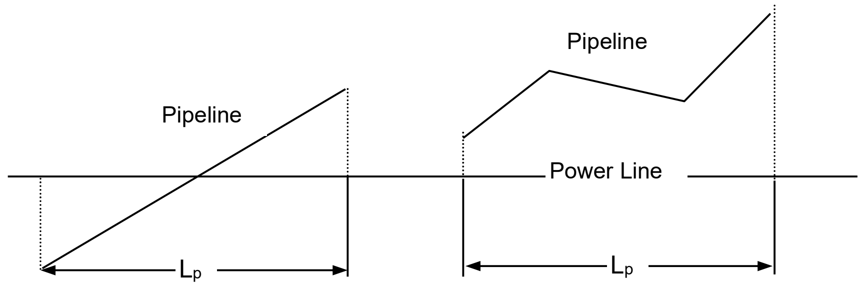


Figure 3: Exposure length L_p for crossings and non-parallel exposures

Table 3: Approximate values of screening factors for inductive coupling

Screening factor of	**Screening factor**
earth wires of power lines	
a) single earth wire	
• ACSR, dc resistance < 0,5 Ω/km	0,70
• 19/2.7 mm steel, dc resistance < 2,0 Ω/km	0,90
• 7/3.51 mm steel, dc resistance < 3,0 Ω/km	0,95
b) double earth wire	
• ACSR, dc resistance < 0,5 Ω/km	0,55
• 19/2.7 mm steel, dc resistance < 2,0 Ω/km	0,80
• 7/3.51 mm steel, dc resistance < 3,0 Ω/km	0,85
MV/HV cables (sheath cross section in mm^2)	
a) lead sheath cable (PILC)	
• 11 kV - 44 kV, 200 mm^2	0,8
• 66 kV - 132 kV, 240 mm^2	0,7
b) aluminium sheath cable (XLPE)	
• 11 kV - 44 kV, 200 mm^2	0,3
• 66 kV - 132 kV, 240 mm^2	0,2
infrastructure	
a) urban environment (urban factor, k_u)	
• soil resistivity 10 Ω.m – 150 Ω.m	0,45
• soil resistivity 150 Ω.m – 1500 Ω.m	0,35
• soil resistivity 1500 Ω.m – 10000 Ω.m	0,25
b) rural environment	1,0

Eqns (2) and (3) are applicable only for relatively short exposures, $L_p \leq 20$ km for perfectly insulated pipelines. On practical lines with standard coatings, when L_p exceeds 20 km the coating leakage will prevent any further increase in the pipeline voltage, irrespective of the additional exposure length (see 3.6.9). Hence when $L_p > 20$ km, the value of a_i determined for $L_p = 20$ km may be applied. Furthermore, when the calculated value of a_i exceeds 10 km, a zone width limit of $a_i = 10$ km may be applied, irrespective of the parameters used.

The zone width a_i calculated from Eqn (2) for some typical scenarios is shown in Figs 4 – 5.

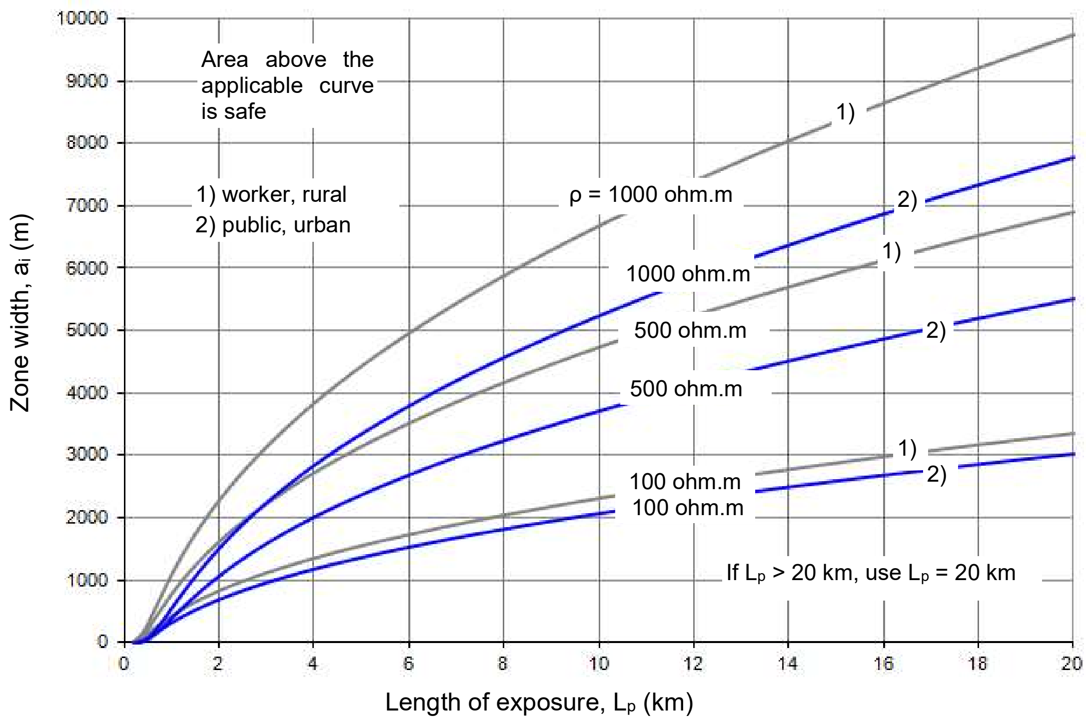


Figure 4: Separation distance vs. exposure length for urban and rural overhead lines (10 kA earth fault, 0.2 sec duration)

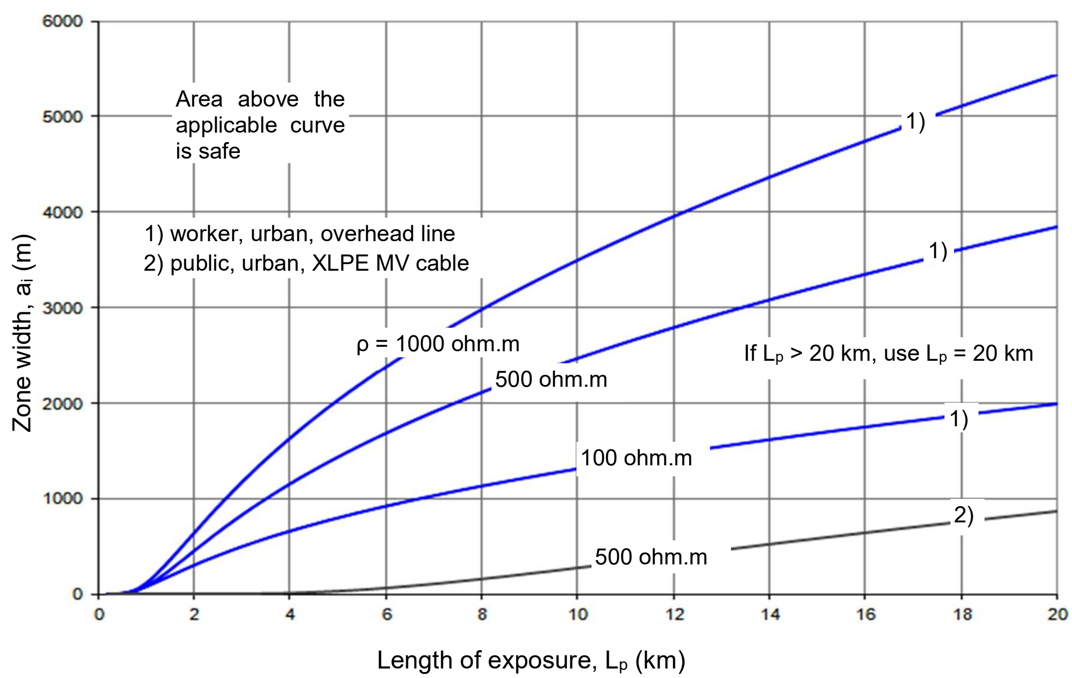


Figure 5: Separation distance vs. exposure length for urban power lines (10 kA earth fault on overhead line, 0.2 sec duration) (360 A earth fault on MV cable, 20 sec duration)

3.4.2.2 ZOI from substation earthing grids and power lines due to conductive coupling

a) Lightning arc

Arcing between a power line tower's footing and a buried pipeline can result from a lightning strike to the tower. The arc distance as a function of soil resistivity ρ was given by Sunde [28] as:

$$S_{arc} = 0.08 \sqrt{I_{arc} \cdot \rho} \quad \text{if } \rho < 100 \text{ ohm.m} \quad [m] \quad (4)$$

$$S_{arc} = 0.047 \sqrt{I_{arc} \cdot \rho} \quad \text{if } \rho > 1000 \text{ ohm.m} \quad [m] \quad (5)$$

where I_{arc} is the lightning discharge current in kA

For soil resistivity in the intermediate range 100 – 1000 ohm.m, Eqn (4) should be used to calculate the arc distance.

With a 100 kA lightning discharge current (a value not exceeded in 95% of cases), S_{arc} ranges from 8 m to 25 m for soil resistivity between 100 ohm.m and 1000 ohm.m.

Being of very short duration (typically less than 100 µsec), lightning arcs not followed by a power arc generally do not result in pipe wall damage. However, the coating can be damaged, and the lightning surge can travel for some distance on the pipeline, which can damage electronic equipment (e.g. CP systems) and could present a safety risk for maintenance personnel (e.g. a worker inside a valve chamber).

Due to several factors this safety risk is generally considered acceptable. These factors include the dilution of current due to other available discharge pathways, rapid dissipation of the surge current along the pipeline due to the pipe-to-earth capacitance, increased human tolerance of pulses of very short duration, and safety protocol that prohibits outdoor maintenance work when there is thunderstorm activity.

As a precaution however, for pipelines encroaching inside the arc distance, all valve chambers within 2 km of this point should be equipped with internal gradient control mats and surge protectors (see B.3, Annex B). CP systems should also be equipped with surge protectors (see 3.3.6).

b) Power arc

Lightning striking a power line tower can initiate an a.c. earth fault and then a power arc can develop. This type of arc is the most serious as this can cause melting and rupture of the pipeline wall.

According to research done by the CEA [29], the distance an a.c. earth fault can be sustained in soil pre-ionized by a lightning arc is:

$$S_{arc} = 0.1058 \cdot V - 0.0137 \quad [m] \quad (6)$$

where V is the voltage of the tower or earthing grid during a fault, in kV r.m.s.

An a.c. earth fault arc not initiated by lightning (but for instance by insulator failure) can be established and sustained over a distance [29]:

$$S_{arc} = 0.1383 \cdot V - 2.6 \quad [m] \quad (7)$$

The voltage V applied in Eqn (6) or (7) should correspond to the tower's (or earthing grid's) potential rise during an earth fault. Substation grids are normally designed with a 5 kV EPR limit, and on towers equipped with earth wires the voltage will rarely exceed 30 kV r.m.s. Adopting a maximum value of 40 kV r.m.s. to include any inductive coupling effect, the minimum allowable separation distances between pipelines and earthing grids or towers to prevent a power arc is 4.22 m, being the greater of:

$S_{arc} = 0.1058 \cdot 40 - 0.0137 = 4.22$ m from Eqn (6), and

$S_{arc} = 0.1383 \cdot 40 - 2.6 = 2.93$ m from Eqn (7).

On towers *without* earth wires, the voltage can exceed 40 kV r.m.s. during a fault. Here the full phase-to-earth voltage should be applied and, in this case, Eqn (7) may yield a larger distance than Eqn (6).

Separation distances calculated using these equations apply to the closest proximity between the pipeline and any earthed structure of the power system, including re-enforced tower foundations, guy wire anchors, counterpoises, sacrificial anodes and substation earthing grids and fences.

c) Earth potential rise

It is also necessary to consider the safety aspect of the earth potential distribution around the faulted tower or grid during an earth fault. With the normal pipeline potential being close to the reference potential of remote earth (i.e. zero potential), the full EPR at the location of the pipeline is applied across its coating, or to a person in simultaneous contact with the pipeline and earth. The unsafe zone extends to a distance where the EPR has reduced to safe levels (see Fig 6).

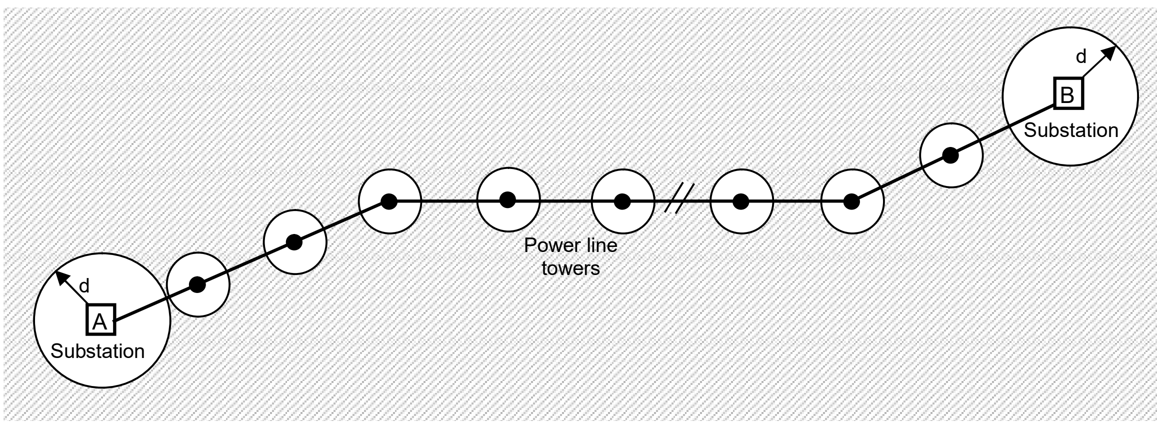


Figure 6: Zone of influence for conductive coupling

The zone size is dependent on the magnitude of the fault current, the resistance of the earthing grid or tower footing, the resistivity of the soil, the fault duration and the corresponding voltage limit. Earth wires on power lines decrease the fault resistance which increases the fault current magnitude, but by distributing this current to multiple towers decrease the zone size for individual towers.

The pre-calculated values of Table 4 should be applied for earthing grids of a.c. substations, and the pre-calculated values of Table 5 for power line poles, masts or towers. These values were calculated using ITU-T REC K.68 methodology. A touch voltage limit of 160 V r.m.s. and 300 V r.m.s. is used for public and authorized exposure respectively, as applicable for a 0.2 sec fault duration.

For other voltage limits, the zone distances in Table 4 and Table 5 can be changed in direct proportion. For example, from Table 5, the zone distance d for a power line tower with steel earth wires in a rural area with 500 ohm.m soil is 460 m, for public exposure. Supposing that a fault duration of 0.5 seconds is applicable, the exposure limit is reduced from 160 V r.m.s. to 60 V r.m.s (see Table 1). The zone distance d then becomes:

$$d = 460 \cdot 160/60 = 1\ 227 \text{ m}$$

In the case of fault current levels other than those indicated in Table 5, the zone sizes are changed in a similar manner. Thus, for the example above, if the actual fault current level is not 10 kA but 5 kA, the zone distance d becomes:

$$d = 1\ 227 \cdot 5/10 = 614 \text{ m}$$

Table 4: Zone of influence for conductive coupling from substation earthing grid (0.2 s fault duration)

Earthing grid dimensions m **and EPR assumed during a fault** [kV]	**Zone distance d from edge of earthing grid** [m]			
	Exposure / environment			
	General public 160 V r.m.s. limit		**Authorised personnel** 300 V r.m.s. limit	
	urban	**rural**	**urban**	**rural**
10 m x 10 m 10 kV	120	260	57	140
30 m x 30 m 10 kV	340	780	172	400
50 m x 50 m 10 kV	570	1 300	290	670
200 m x 200 m 5 kV	1 100	2 600	500	1 300
500 m x 500 m 5 kV	2 700	6 400	1 300	3 300

Table 5: Zone of influence for conductive coupling from power line towers (0.2 s fault duration)

Type of earth wire(s) on power line	**Soil resistivity** [ohm.m]	**Fault current assumed** [kA]	**Zone distance d from tower footing** [m]			
			Exposure / environment			
			General public 160 V r.m.s. limit		**Authorized personnel** 300 V r.m.s. limit	
			urban	**rural**	**urban**	**rural**
none (see note)	50	0,36	10	20	6	13
	500	0,36	60	180	32	95
	5 000	0,03	80	300	38	152
steel	50	10	110	240	57	125
	500	10	160	460	82	230
	5 000	10	160	650	97	330
ACSR	50	10	40	80	20	44
	500	10	55	150	25	76
	5 000	10	55	220	32	114
NOTE: Only applicable to a small number of MV power lines.						

3.4.2.3 ZOI from overhead power lines due to capacitive coupling

Capacitive coupling is only of consequence for pipelines or sections of pipeline above ground and insulated from earth. Normally this is limited to construction activity, for example during lifting and lowering in operations of coated pipeline sections, or sections stored on skids. Underneath power lines, large electrostatic voltages can develop on such sections, which can discharge to earth through a person touching the section.

The power-to-pipeline capacitance (and hence the energy transferred) is very small however, and when the safety distances (see 3.8) are observed, the discharge current limit for authorised personnel of 10 mA r.m.s. will not be exceeded for sections of normal length. Still, it could be discernible as a shock like that from electrostatic electricity and could cause a secondary safety hazard if someone working on the pipeline overreacted to this. Moreover, metal contact would produce a spark that could ignite a fuel vapour.

For long, insulated pipelines installed above ground on plinths alongside or underneath power lines, the discharge current could reach 10 mA r.m.s. for lengths in excess of 200 m. This can however be readily mitigated by earthing; even a relatively high resistance earth (100 ohm - 200 ohm) will totally neutralize any capacitive coupling hazard.

The zone of influence is in this case limited to the power line servitude.

3.4.2.4 ZOI from anode ground beds and pipelines due to d.c. leakage

a) Anode ground beds

For homogenous soil, the distance d, from an anode comprising a single horizontal or vertical conductor installed a coke backfill, beyond which the d.c. potential of the soil will be below the 200 mV limit may be calculated using the equation [27]:

$$d = 2.5 \cdot V_a \cdot (L_a)^{0.65} \qquad [\text{m}] \qquad (8)$$

where:

- V_a is the maximum d.c. voltage applied to the anode [V],
- L_a is the length of the anode [m].

With the anode length adjusted according to soil resistivity, d can vary from a few hundred metres in low resistivity soils to several kilometres in high resistivity soils, for typical CP current requirements.

b) Pipelines

Considering a semi-infinite, straight, ICCP - protected pipeline with evenly distributed coating defects, buried in homogenous soil with 1 m cover, the difference ΔU in the surface potential between two points, one separated by x [m] and one separated by x + s [m] from the pipeline for x ≥ 1 m, is given by [27]:

$$\Delta U = J \cdot \rho \cdot d \cdot \ln\left(\frac{x+s}{x}\right) \qquad [\text{V}] \qquad (9)$$

rearranging:

$$x = s \cdot \left(e^{\frac{\Delta U}{J\rho d}} - 1\right) \qquad [\text{m}] \qquad (10)$$

where:

- J is the protection current density, [A/m²],
- ρ is the soil resistivity, [ohm.m],
- d is the pipeline diameter, [m],
- s is the span distance between subsequent towers, [m].

ΔU can be regarded as the driving potential between two towers close to the pipeline. For a d.c. potential shift of 200 mV to develop at the tower footing, ΔU must be at least 400 mV over a full span. The resulting minimum lateral separation distance x to be applied for a power line with 400 m spans approaching the pipeline at 90˚ is as indicated in Table 6, for a large-bore (2 m diameter) pipeline, as a function of protection current density and soil resistivity:

Table 6: Zone of influence for d.c. leakage (2 m ø pipe, perpendicular crossing, 400 m span)

Protection current density µA/m²	**Zone distance x from pipeline** [m] **for soil resistivity of**			
	50 Ω.m	500 Ω.m	1000 Ω.m	5000 Ω.m
10	no influence	no influence	no influence	10
50	no influence	no influence	10	330
100	no influence	10	65	820
500	no influence	330	820	see Note
1 000	10	820	see Note	see Note
5 000	330	see Note	see Note	see Note
Note: With normal CP voltages, this current density cannot be achieved in this soil				

The protection current density is determined not as much by the resistivity of the coating material, as by the imperfections and defects in the coating and joints (see 3.6.5). Bitumous coatings are prone to such imperfections and to water absorption, which can increase current demand with the age of the pipeline. The protection current density for existing bitumen and tape wrap, 40-year-old Transnet pipelines can reach up to 5 000 µA/m2 in low soil resistivity regions.

With modern pipeline coatings of high mechanical strength (e.g. polyurethane or polyethylene) usually only a few widely spaced defects occur. A current density in the range 10 - 50 µA/m2 is regarded as normal, although 500 µA/m2 is usually allowed for in the CP system design.

When the power line approaches or crosses the pipeline at an oblique angle, the full span distance s [m] in Eqn (10) is to be replaced by s’ [m], the difference in lateral separation between the pipeline and the two nearest towers (see fig 7). The zone distance x is then decreased.

When the angle θ between the pipeline and power line nears 0˚, the distance s’ tends to zero, and it follows that zone distance x also approaches zero. For parallel runs, assuming the coating defects are evenly distributed, the surface potential difference between towers also tends to zero. Whilst this is valid for evenly distributed coating defects, a large defect close to one tower would introduce a gradient. To account for this, a minimum angle of 30˚ should be applied when calculating s’.

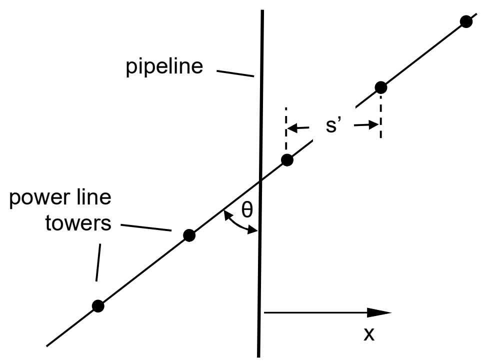


Figure 7: Distance s’ between towers for oblique approaches and crossings

3.4.2.5 ZOI from large photovoltaic installations due to d.c. leakage from PV modules

Photovoltaic installations invariably have some d.c. leakage from individual cells to module frames, which can be exacerbated by degraded sealants and water ingress. In the case of large, utility-scale PV systems the accumulated effect can cause stray current corrosion on underground metallic pipelines [36]. Whilst various international standards are applied that define the minimum insulation resistance of PV cells, d.c. leakage currents will inevitably increase as systems age, and can also result from undetected d.c. ground faults (also see 3.7.1.12 and fig 23).

The severity of this problem is under investigation and there are no standards yet that define a safe distance from a PV installation. For the time being, the ZOI that can be applied is the complete footprint of the solar installation and the associated d.c. cabling and substations.

3.4.3 Risk assessment and tolerable risk levels

The risk of hazardous contact scenarios involving power line faults and authorized pipeline maintenance personnel can sometimes be so low that no mitigation is required. Guidance on acceptable risk can be found in SANS 62305-2, the South African standard for lightning risk assessment, which is used to determine if buildings and structures require LPS or lightning protection systems. From this standard, the tolerable risk of a lightning flash causing a fatality inside or next to a structure is:

- 1 in 100 000, or 10^{-5} per annum, with no warning signs, or
- 1 in 10 000, or 10^{-4} per annum, with clear warning signs attached to the hazardous structure.

The same risk levels may be applied for earth faults causing step or touch voltages above the safety limits on pipeline structures.

For pipelines subject to power line induction, the risk of hazardous exposure of authorized personnel depends on (i) the risk of an earth fault occurring in a specific section of the power line (such that dangerous voltages would result on a pipeline), and (ii) the duration of exposure by individuals to the section of the pipeline (or its attachments) where the dangerous voltages can occur.

The risk of power line faults can be established from historical data for the specific line in question, or from generic data for the line type, expressed as the annual fault rate /100 km (e.g. from CIGRE [14], see table 7).

Table 7: CIGRE earth fault statistics (from [14])

Voltage range kV	Earth fault frequency (per 100 km · year)	
	with earth wires	*without earth wires*
110 – 150	3.27	3.77
187 – 275	2.21	13.4
320 - 500	1.40	13.8

Annual exposure time (in hours) that individuals could be in contact with the hazardous pipeline section should be available from the PO, based on the maintenance schedule. This should include all activities involving pipe contact on the hazardous section, averaged over the pipeline's functional lifetime, e.g.

- valve operations and maintenance,
- CP test point measurements,
- leak repair,
- coating inspections and repair.

The risk of a fatality is given by:

$$R_{fatality} = P_{fib} \cdot P_{coincidence} \quad [p.a.] \qquad (11)$$

where

$$P_{coincidence} = N \cdot \frac{t_{exp}\,[h]}{8760} \quad [p.a.] \qquad (12)$$

$$N = \frac{\text{Annual fault rate [/100 km]} \cdot \text{Hazardous power line length [km]}}{100} \qquad (13)$$

and

P_{fib} is the probability of fibrillation

$P_{coincidence}$ is the probability that a person is touching the pipeline when a fault occurs

N is the annual number of faults on the power line section affecting the pipeline

t_{exp} is the exposure time, in hours

P_{fib} depends on several factors including the health of the individual, event duration, the discharge current level, the discharge path and on the time of occurrence in the cardiac cycle. The voltage limits of table 1 are based on the IEC C1 curve (see 3.3.1) representing a P_{fib} of 5%, however once these limits are exceeded, P_{fib} rapidly increases to above 50%.

Conservative results will be obtained when the probability of a fatality is assumed to be 100%, or P_{fib} = 1, when the limits of table 1 are exceeded.

The power line length used for the calculation should be limited to the section or towers that would cause unsafe pipeline voltages during an earth fault at that point. In the case of crossings at angles greater than 60°, this applies only to towers closest to the pipeline, taking due account of current distribution to adjacent towers through the earth wires (see fig 12). For an initial assessment, at least 5 towers on either side of the crossing should be included, for lines equipped with earth wires. The length of pipeline affected depends on the ZOI of the faulted tower, as determined from par 3.4.2.2 (c).

With parallelisms, the hazardous power line length could extend beyond the parallel section. Provided inductive coupling is an issue (from par 3.4.2.1), the full length of the power line should be taken into account, for an initial assessment.

Any hazardous contact scenario involving authorized personnel where $R_{fatality}$ can be shown from Eqn (11) to be below 10^{-5} p.a., or below 10^{-4} p.a. with clear warning signs applied, may be accepted without any further coupling calculations or AC mitigation measures.

As an example, consider a water pipeline of 15 km length crossing a rural 132 kV distribution line at 90°. Assume that the power line fault level is 10 kA, the clearance time is 0.5 seconds, the fault rate is 3.8 faults/100 km p.a., the line is equipped with steel earth wires and the average span length is 320 m. Further, assume that the pipeline is accessible to authorized personnel only with a total annual exposure time of 16 hours on average, the valve chambers and test posts are evenly distributed, the crossing occurs just 20 m from the closest tower and the soil resistivity is unknown.

From table 5, the ZOI for conductive coupling for a 0.2 sec exposure time is 330 m (applying the highest soil resistivity level). For a 0.5 sec exposure time, the touch voltage limit for authorized personnel must be reduced from 300 V r.m.s. to 105 V r.m.s. (as per table 1). From 3.4.2.2 (c), the adjusted ZOI follows as:

$$d = (300 \text{ V r.m.s.} / 105 \text{ V r.m.s.}) \cdot 330 \text{ m} = 943 \text{ m} \quad \text{(distance from tower footings)}$$

With a tower near the crossing, the affected length of the pipeline is twice this distance, 1.89 km. The total annual exposure time for this section is:

$$t_{exp} = (1.89 \text{ km} / 15 \text{ km}) \cdot 16 \text{ h} = 2.02 \text{ h}$$

By including 10 towers (5 each side of the crossing) with 320 m spans, the length of power line where a fault could cause hazardous voltages is 3.2 km.

From Eqns (12) - (13):

$N = (3.8 \cdot 3.2\ \text{km}) / 100\ \text{km} = 0.122$

$P_{coincidence} = 0.122 \cdot 2.02\ \text{h} / 8760\ \text{h} = 2.81 \times 10^{-5}$

Applying Eqn (11) with P_{fib} =1 gives:

$R_{fatality} = 1 \cdot 2.81 \times 10^{-5} = 2.81 \times 10^{-5}$ p.a. ($>10^{-5}$)

Thus, the risk from the distribution line in this example is higher than tolerable without warning signs. The pipeline would require either warnings signs or mitigation measures that would limit the touch voltages to 105 V r.m.s. inside the ZOI.

Supposing that the line is instead a 400 kV transmission line with a fault level of 15 kA, a clearance time of 0.2 sec (with a corresponding touch voltage limit of 300 V r.m.s.), a fault rate of 1.4 faults /100 km p.a. and an average span length of 400 m, then repeating the calculation above yields:

$d = (15\ \text{kA}/10\ \text{kA}) \cdot 330\ \text{m} = 495\ \text{m};\ \times 2 = 0.99\ \text{km}$

$t_{exp} = (0.99\ \text{km} / 15\ \text{km}) \cdot 16\ \text{h} = 1.06\ \text{h}$

$N = (1.4 \cdot 4\ \text{km}) / 100\ \text{km} = 0.056$

$P_{coincidence} = 0.056 \cdot 1.06\ \text{h} / 8760\ \text{h} = 6.78 \times 10^{-6}$

$R_{fatality} = 1 \cdot 6.78 \times 10^{-6} = 6.78 \times 10^{-6}$ p.a. ($<10^{-5}$)

For the case of this transmission line then, the risk to the pipeline maintenance personnel is tolerable and warning signs or AC mitigation measures are not required.

For cases where valve chambers and test posts are not evenly distributed, the actual number falling inside the ZOI should be counted, and appropriate exposure times applied.

Note that this approach applies only to human safety, and not to the risk of equipment damage.

Because public exposure time estimates can be very unreliable, use of this approach for pipelines exposed to the public is not recommended.

It is also not applicable for steady state induction scenarios.

3.5 Soil Resistivity Measurements

3.5.1 General background

Soil resistivity has a significant influence on the level of conductive and inductive coupling. Calculations for voltages resulting from inductive coupling at 50 Hz can be in error by up to a factor of 2 if the soil resistivity value is incorrect. Conductive coupling is even more sensitive to the soil resistivity and the possible error is much larger.

Soil resistivity can vary from about 10 ohm.m to 10 000 ohm.m depending on the type and age of the formation. With electrical conduction in soils being largely electrolytic, it is considerably affected by the amount of soluble salts and other minerals present. It increases abruptly when the moisture content drops below 15 % the soil's weight, or when the soil temperature drops below freezing point.

Numerous tables can be found in the literature with soil resistivity ranges based on the type of soil formation. The use of such tables is generally not recommended for coupling studies, partly due to the possibility of stratification, which is not visible from the surface, and partly due to the possible incorrect assessment of the soil type due to lack of experience.

Soil is very rarely homogenous in a given area; it is more likely to exhibit variation with depth owing to layers of different type and structure, referred to as stratification. Stratification can increase the size of the ZOI resulting from conducted coupling, particularly when thin layer(s) of low resistivity overlay high resistivity bedrock. Lateral changes also occur, but in comparison to the vertical ones, these changes usually are more gradual.

With Southern Africa's temperate climate, ground frost to any significant depth is not common, and the worst inductive or conductive coupling usually occurs in the dry season, i.e. when soil resistivity is at its highest. This is therefore the preferred time for measurements, and outside the dry season, allowance should be made for seasonal variation. One Eskom study showed resistivity increases of up to 82% for the surface layers (0.5 m - 2 m) and 49% for the deeper layers (2 m – 50 m) during the dry season [35].

3.5.2 Measurement methods

For inductive and conductive coupling calculations, the soil resistivity measurement method used must penetrate into the deep soil layers to establish if there are any important variations of resistivity with depth. The Wenner four - probe method as described in SANS 10199 (2004), par 3.2.2 or in IEEE 80 (2000), par 13.3 is the simplest and most used method. Either a.c. or d.c. sounding equipment can be used for this purpose. The probe spacing should be according to tables 8 - 10, depending on the situation under study.

Table 8: Wenner soil resistivity soundings for inductive coupling studies

Probe spacing **a** [m]	**Specific depth** **D = 0.8·a** [m]	**Tester reading** **R** [ohm]	**Geometric factor** **K = 2π·a** [m]	**Apparent resistivity** ρ_a **= K·R** [ohm.m]
0.5	0.4		3.14	
1	0.8		6.28	
3	2.4		18.85	
10	8		62.83	
20	16		125.7	
30	24		188.5	
50	40		314.2	
70	56		439.8	
100	80		628.3	
120	96		754.0	

Table 9: Wenner soil resistivity soundings for conductive coupling studies

Probe spacing **a** [m]	Specific depth **D = 0.8·a** [m]	Tester reading **R** [ohm]	Geometric factor **K = 2π·a** [m]	Apparent resistivity **ρa = K·R** [ohm.m]
0.5	0.4		3.14	
1	0.8		6.28	
2	1.6		12.57	
4	3.2		25.13	
10	8		62.83	
20	16		125.7	
30	24		188.5	

Table 10: Wenner soil resistivity sounding for soil corrosivity studies

Probe spacing **a** [m]	Specific depth **D = 0.8·a** [m]	Tester reading **R** [ohm]	Geometric factor **K = 2π·a** [m]	Apparent resistivity **ρa = K·R** [ohm.m]
2	1.6		12.57	

With the Wenner method, soil resistivity soundings at a given probe spacing provide a measure of the apparent resistivity, ρ_a, taking into account soil layers to a depth of about 80 % of the probe spacing. Unless the soil is homogenous, ρ_a will not be constant with increasing depth. From the sounding data it is possible to deduce how many soil layers are present, and what the thickness and resistivity of each layer is. This relatively complex calculation requires the use of computer software. A typical example is shown in Fig 8.

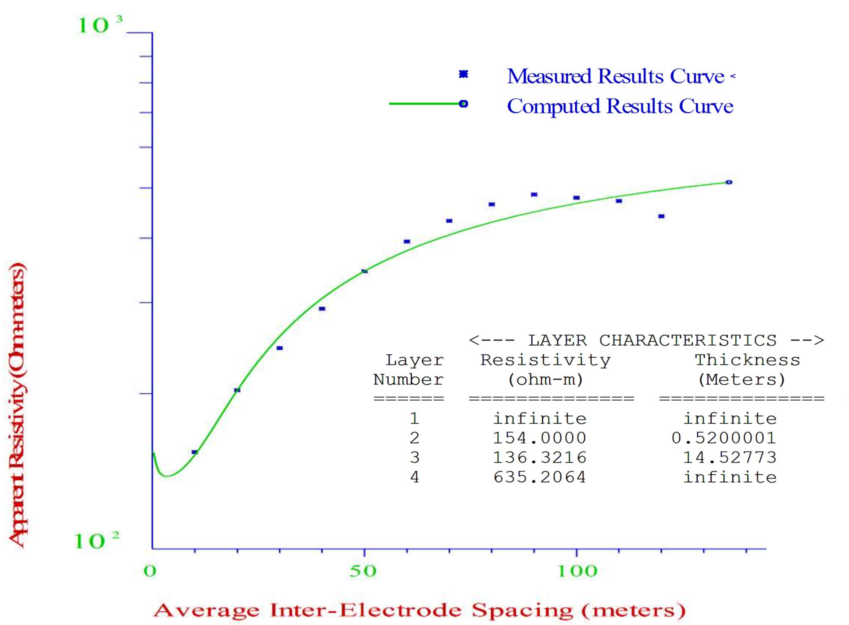


Figure 8: Example of apparent resistivity graph and calculated soil layers

A further development of the Wenner method is CVES (Continuous Vertical Electrical Sounding), which uses a much larger linear array of probes and enables the calculation of two-dimensional soil resistivity map, used for example to identify underground water, mineral pockets etc.

When used for inductive or conductive coupling studies, a typical CVES array would consist of 36 probes at 10 m intervals, providing penetration ranging from about 8 m to 100 m. When the surface resistivity and the resistivity at pipe depth is also required, a measurement with the probes at 0.5 m intervals is also needed, or alternately three conventional Wenner measurements at 0.5 m, 1 m and at 3 m probe spacings.

Another alternative, non – invasive method for measuring subsurface resistivity employs inductive electromagnetic (EM) probes. Without the requirement of contact with the soil, these devices can be mounted on a vehicle trailer facilitating fast readings with high spatial resolution. Penetration depth varies from 1.5 m to 60 m, depending on coil spacing, transmitter power and polarization.

3.5.3 Selection of measurement sites

The selection of sounding sites depends on the study under consideration.

a) For **inductive coupling studies**, the distance between DSR sounding sites along a parallelism should not exceed 5 km. For short parallelisms (< 10 km) this should be reduced to 2 km, to ensure a better average. These soundings should be done with the probe array perpendicular to the power line axis and centred near this axis, well away from the power line towers and guy wires (preferably at midspan).

b) For **conductive coupling studies** where no parallelism is present, only a single DSR sounding site is required. The probe array should start near the centre of the side of the substation grid or tower footing facing the pipeline, at a point separated some 10 m from the substation fence or footing and move perpendicularly outwards.

c) For **soil corrosivity studies**, surface resistivity measurements are recommended at intervals not exceeding 100 m along the intended pipeline route. In wet or clay settings, the interval should be reduced to 50 m or less and should include the worst affected locations. In other settings where different soil conditions are encountered over shorter distances, a practical criterion is to halve the survey interval if any two successive readings differ by more than a factor of 2.

   These measurements are essential for the design of the CP system and are also required for an assessment of the a.c.- induced corrosion risk for pipelines subject to steady state induction. Measurements at smaller intervals can also be very useful in the design of a.c. mitigation measures and could lead to significant savings in the total length of gradient control wire required. In this respect, measurements made with EM probes offer the highest resolution available.

3.5.4 Measurement precautions

a) Avoid sounding sites with the probe array parallel or quasi-parallel to metallic structures such as fences, existing pipelines, underground cables, railways, earthing grids or other man-made structures if possible. If the site must cross a pipeline or fence, the sounding should be done with the probe array perpendicular to the pipeline or fence.

b) Where possible, the direction of the array should be parallel to the geological strike of the site. The direction of the strike will usually be shown by lines of outcropping rock (ref. SANS 10199).

c) Wenner soundings should be analysed on site to enable identification of measurement errors, due for example to leakage, anomalous effects at the probes, a.c. induction, damaged leads etc. If the apparent resistivity is above 10 000 ohm.m or below 10 ohm.m, or differs greatly from a given trend in geologically similar conditions, the sounding should be regarded as suspect.

d) To ensure adequate measurement resolution with pin spacings of 30 m and larger, instruments should be rated at least 50 V / 50 mA for a.c. units, or 200 V / 125 mA for d.c. units.

e) Inductive EM probes may be subject to interference near power lines due to corona noise or from power line carriers in the frequency band of the instrument's receiver.

3.6 Calculation of pipeline voltages

3.6.1 General

The theory of capacitive, inductive and conductive coupling is comprehensively covered in CIGRE Guide 95, "Guide on the Influence of High Voltage AC Power Systems on Metallic Pipelines" [14].

A metallic pipeline subject to inductive influence can be modelled by multiple discrete sections, each consisting of a series impedance representing the resistance and inductive reactance of the pipe wall, a shunt impedance representing the leakage resistance and capacitive reactance, and a voltage source representing the emf developed in the section by the power line currents, which may be calculated with the formulas developed by Carson and Pollaczek.

In this form the pipeline closely resembles a leaky transmission line, and the theory for calculating the currents and voltages on transmission lines can be applied. In this sense, the transmission line concepts of propagation constant, electric length and characteristic impedance also become valid for a pipeline.

This model further enables the study of mitigation measures. For instance, an earthed electrode connected to the pipeline at a given point will reduce the corresponding section's shunt resistance to earth, whereas an insulating flange in the pipeline will increase the section's series resistance. By altering these resistances accordingly in the model, the effect of the measure(s) on the pipeline currents and voltages can be readily observed.

The effect of capacitive coupling can be predicted using the Maxwell potential coefficient method. This is necessary only for above-ground pipelines or pipeline sections inside the servitude without regular earthing points.

The effect of conductive coupling can be modelled using the concept of an equivalent hemispheric electrode for the tower footing or earth grid under study, although this method provides only limited accuracy near the electrode, or when the soil is stratified. More detailed, finite element computer models take account of the soil layers and exact electrode shape and can accurately predict the potential transfer to a pipeline.

In general, for realistic exposures, analysis of the respective coupling components requires the use of suitable computer software.

3.6.2 Software packages

Several software packages for the calculation of the voltages on pipelines subject to power line coupling are commercially available. Software selected for this purpose should meet the following minimum requirements:

a) Inductive coupling calculations:

- calculation of pipeline voltage and currents during steady state nominal and emergency load conditions with multiple adjacent power lines,
- calculation of pipeline voltage and currents during fault conditions at any point on the power line,
- account for tower configuration, conductor sag, earth wires and phase transpositions,
- capable of modelling the effect of earthing points, insulating flanges, gradient control wires, drainage units, sacrificial anodes and resistive bonds on the pipeline.

b) Capacitive coupling calculations:

- calculation of the voltage of pipelines above ground subject to capacitive coupling from an overhead power line.

c) Conductive coupling calculations:

- calculation of multi-layer soil model from resistivity measurements,
- earth potential rise (EPR) around a faulted tower or substation grid,

- step potential, touch potential and coating stress on a pipeline traversing the EPR zone.

d) d.c. leakage calculations:

- calculation of the d.c. potential distribution around ICCP-equipped pipelines and ground beds.

e) Fully benchmarked against known calculation or measurement results.

For proper utilisation of these software packages, training of personnel through courses approved by the software developer are essential. Personnel using the software should also have fundamental training in electrical power networks, fault current calculations and electromagnetic coupling phenomena.

3.6.3 Inducing currents on a.c. power lines

3.6.3.1 Currents during normal operation

a) Overhead phase conductor ratings

For inductive coupling calculations under normal operating conditions, the current rating of the phase conductors should be applied as inducing current, provided the load is not limited by other considerations (see par (c) and (d) below). Phase conductor rating is a function of the type and number of sub-conductors in the bundle and the design temperature of the power line. Table 11 indicates the ratings for standard Eskom overhead conductor types, from ST 240-147806256 [13].

Rate A and Rate B represent the maximum operating current for normal load conditions and emergency load (N-1) conditions respectively. Eskom's EHV designs are however very conservative, and Rate A is normally not exceeded under emergency load conditions. Rate A can then be used for calculating the pipeline voltage when checking against the safety limit (3.3.4). This also applies to most HV lines, but in cases where this cannot be confirmed, Rate B should be used instead.

Rate C (not shown in Table 11) should not be used for coupling calculations as the probability of its application in practice is extremely low.

A benchmark design temperature of 50°C is applicable for most Eskom's lines. A limited number of lines are templated at higher temperatures, e.g. 60°C, 70°C or 80°C, allowing for increased current ratings. The corresponding increase in conductor sag is then accounted for in the tower designs.

b) Cable conductor ratings

For XLPE and PILC cables, the conductor ratings depend on the copper cross section as well as the configuration (trefoil, single core or three core) and applicable de-rating factors, depending on the method of installation. These ratings should be obtained from the relevant department in Eskom on a case-by-case basis.

c) Terminal equipment limitations

The emergency load on power lines is sometimes restricted by the capacity of the terminal equipment (most often by the transformers). However, this equipment could be re-configured when additional capacity is introduced into the network (from wind or solar plants for example), and in the interest of avoiding costly re-designs, Rate A should generally be regarded as the minimum for pipeline safety calculations. The terminal equipment rating may be applied instead only when there exists a high degree of certainty that no upgrades could occur at some stage in future for the line under consideration.

Table 11: Standard Eskom overhead conductor ratings for 50°C and 70˚C design temperature, from ST 240-147806256 [13]

Conductor type	**Overall diameter** [mm]	**d.c. resistance at 20˚C** [ohm/km]	**Rate A (50°C)** [A r.m.s.]	**Rate B (50°C)** [A r.m.s.]	**Rate A (70°C)** [A r.m.s.]	**Rate B (70°C)** [A r.m.s.]
Acacia	6.24	1.39	108	153	145	194
Squirrel	6.33	1.3677	104	143	138	183
Magpie	6.35	2.707	33	40	58	62
"35"	8.31	0.785	158	216	206	265
Fox	8.37	0.7822	148	203	196	258
Pine	10.83	0.462	219	302	293	385
Mink	10.98	0.4546	206	285	270	361
Oak	13.95	0.279	297	417	391	530
Hare	14.16	0.2733	280	392	376	496
Tiger	16.52	0.2202	322	466	444	593
Ash	17.4	0.184	381	548	523	700
Wolf	18.13	0.1828	363	528	498	671
Elm	18.8	0.1568	424	625	514	712
Chickadee	18.87	0.1427	608	823	559	761
Lynx	19.53	0.1576	401	584	551	742
Pelican	20.70	0.1189	475	698	646	874
Panther	21.00	0.1363	441	642	606	818
Sycamore	22.61	0.11	549	775	725	981
Bear	23.45	0.1093	521	767	706	962
Kingbird	23.90	0.0891	586	831	771	1045
Goat	25.97	0.0891	618	866	813	1102
Antelope	26.73	0.0773	628	921	857	1172
Tern	27.0	0.0718	665	963	894	1231
Yew	28.42	0.0696	761	1073	948	1306
Zebra	28.62	0.0674	710	1022	938	1285
Rail	29.59	0.0598	775	1109	1101	1408
Bunting	33.07	0.0439	881	1324	1180	1643
Bersfort	35.56	0.0421	965	1420	1304	1814
Dinosaur	35.94	0.0437	938	1380	1267	1763
Bull	38.25	0.0334	1150	1654	1517	2117

NOTE: 1) Multiply the rated current by the number of sub-conductors in the bundle

2) Consult ST240-147806256 for different line design temperatures if applicable (e.g. 60°C or 80°C)

d) Loading capacity of long EHV and HV lines

As the length of EHV power lines increases above about 80 km, line voltage drop and stability issues become the limiting factors in loading capacity, instead of the phase conductor's thermal limits. Each line has a characteristic SIL or surge impedance load, which cannot be exceeded economically for lines longer than about 480 km. The SIL is typically 2.5 - 3 times lower than the thermal limit.

In the intermediate 80 - 480 km length range the loading capacity decreases: sharply at first and then more gradually with length. The actual limit is dependent on the level of compensation applied to the network.

For HV lines, the same effect already becomes evident for line lengths of about 20 - 30 km, as shown in fig 9. This figure summarises the load reach of a single-circuit 132kV line for several conductor types, assuming a power factor of 0.9, a thermal limit of 70°C and a maximum volt drop of 8%.

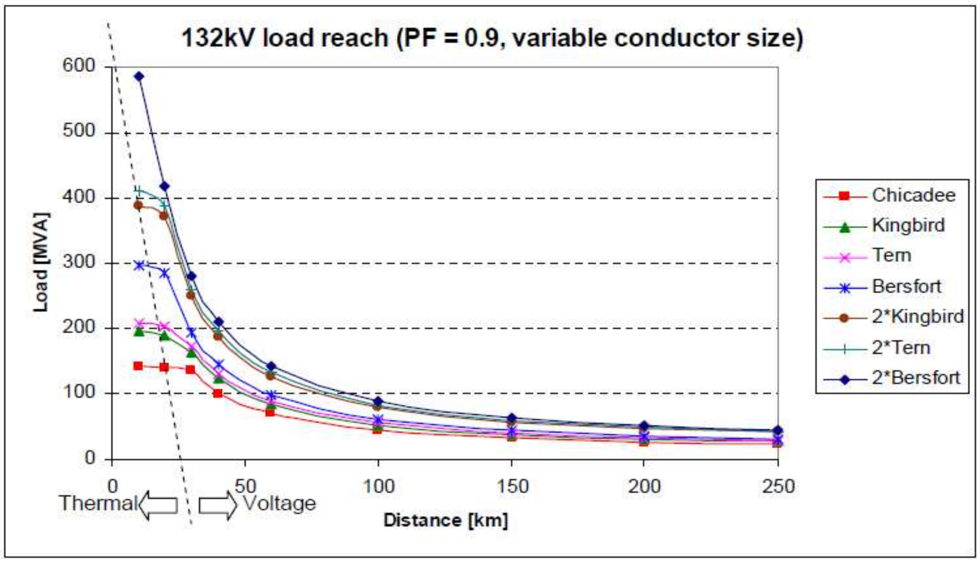


Figure 9: 132 kV line load reach with variation in phase conductor (from DGL34-619)

For inductive coupling calculations involving long lines, the loading limit for the specific line in question should be obtained from the relevant department in Eskom.

e) Applying phase unbalance

The magnitude of the individual phase currents on 3-phase power lines normally lines differ slightly due to different loading per phase. This introduces a zero-sequence current that must return through the earthing system of the power line. Zero-sequence or earth return currents can produce much greater inductive coupling than the balanced component.

The local quality of supply standard (NRS048-2) recommends a maximum of 3% phase current unbalance in supply networks. For pipeline coupling calculations, an unbalance of 3% may hence be assumed. This can be applied directly to the magnitude of one of the phase currents.

For example, from Table 11, Rate A for a Dinosaur sub-conductor at 50°C is 938 A r.m.s, i.e. 2 814 A r.m.s. for a 3- conductor bundle. The resulting phase currents on a RWB – sequence circuit with Triple Dinosaur phase conductors will be:

Red phase: IR = 2 814 + 3% = 2 898 A r.m.s, angle 0˚

White phase: IW = 2 814 A r.m.s, angle -120˚

Blue phase: IB = 2 814 A r.m.s, angle 120˚

This method is sufficiently accurate even though the precise definition of phase unbalance is slightly more complex (see 3.1 in NRS048-2).

f) Effect of transpositions

Transpositions place a different phase closest to the pipeline, normally with the result that, during steady-state induction, the induced pipeline emf is around 120˚ out of phase on either side of the transposition. This produces a pipeline voltage maximum at the transposition (see fig 18).

Because of this important effect on the pipeline voltage profile, it is essential that transpositions are accounted for and that the correct sequence change is applied (a RWB – BRW transposition will have a different effect than a RWB – WRB transposition, for example).

g) Phase sequence of double circuit power lines and multiple power lines

On double circuit power lines, there are several possible phase configurations of the second circuit with respect to the first circuit (see fig 10). The emf induced on the pipeline will be increased or decreased depending on the relative position of the corresponding phases.

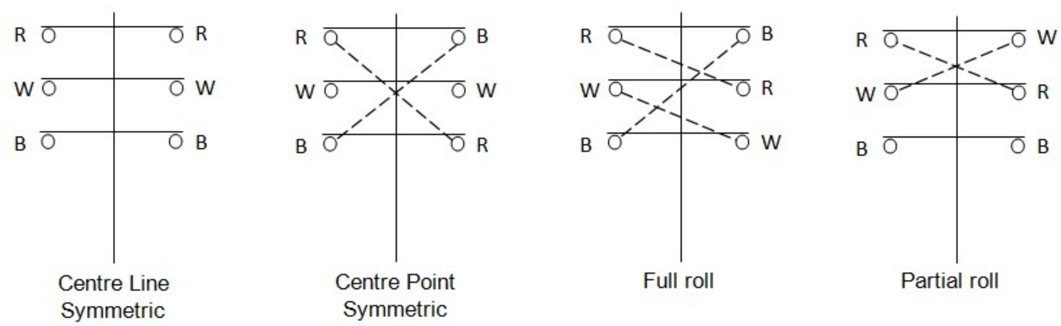


Figure 10: Phase configurations for double circuit vertical power lines

Theoretically, with unidirectional current flow, the highest emf will occur for the centre line symmetric configuration, and the lowest for the centre point symmetric configuration. With equal, balanced circuit loads, the emf produced by the centre point symmetric configuration approaches zero, as the two circuit's emfs are of opposite phase. This must however be investigated for each specific case, as it is also dependent on the tower geometry and the relative position of the pipeline.

In the case of line-in, line-out (LILO) circuits, with current flow in opposite directions, the centre line symmetric configuration will produce the lowest emf and would be the preferred configuration.

Changing the phase configuration is normally not a viable mitigation option except with new lines, and then it must be ensured that no changes will occur on the line over the operational life of the line.

If this cannot be guaranteed, a more conservative approach is to select the worst-case phase combination and design the pipeline mitigation accordingly. The worst-case double circuit induction level may be obtained by doubling the emf induced by the nearest circuit.

For pipelines in servitudes with three or more power lines however, the number of possible combinations to simulate increases greatly. A compounding factor is the phase angle of the zero sequence currents, which can be different on each individual line. The worst case is when all the zero sequence currents are in phase.

For multiple power lines it is therefore simpler to establish the worst-case combination by starting with the line nearest to the pipeline (or the line with the greatest overall influence) and assigning a RWB phase sequence. The next nearest line then added, and the phase sequence of this line adjusted until maximum pipeline voltage is obtained, and then remains fixed. This process is repeated for all lines, each time without any further adjustment of the previous lines.

For all lines, the unbalance is applied to the same phase (e.g. Red).

This procedure effectively ensures the worst-case combination of phases and in-phase addition of all emfs produced by the zero-sequence currents.

3.6.3.2 Currents during faults

a) Sliding fault current profile

On a typical ring-fed power line, the inducing current magnitude is at a maximum for a fault near the substations feeding the line, and at a minimum near the middle of the line, due to the increased line impedance with distance to the fault. This impedance gives rise to the sliding fault current profile of the power line (see Fig 11).

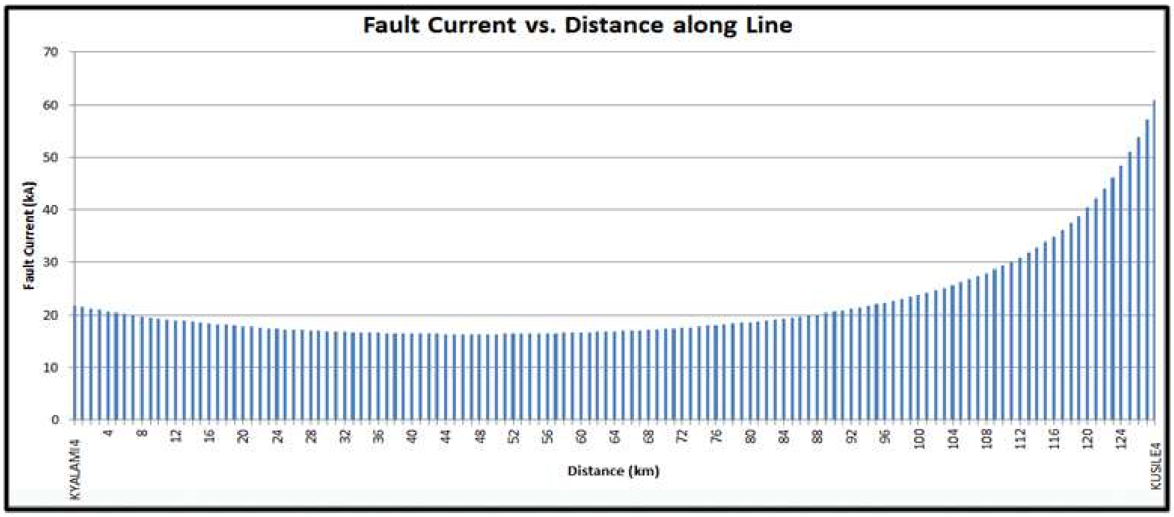


Figure 11: Example of sliding fault current profile, 400 kV line

At the substations, the fault level is determined by the equivalent source impedance, which represents the sum of all impedances of the network between that point and the power generating station(s). In a 3-phase system, this impedance may be represented by its positive, negative and zero sequence components. The sequence components can be calculated for any substation in the network with power systems analysis software such as PSS/E or DigSilent PowerFactory.

To compute the sliding fault current profile for a given line, the substation's equivalent source impedances are required without this line in place. The line's circuit breakers must therefore be temporarily opened in the analysis software when the equivalent source impedances are computed.

The line's fault current profile can be computed from these values and the line data (tower configuration and conductor data, see checklist A.3), using sub-conductor diameter and d.c. resistance from Table 11. Only a 1-phase to earth fault needs to be considered since the residual currents during 2- and 3- phase to earth faults will be of a smaller magnitude.

b) Currents producing tower footing EPR

For power lines equipped with earth wires, the returning fault current is distributed between the faulted tower and the footings of adjacent towers by the earth wires. When calculating the earth potential rise around a tower therefore, this division of the current must be carefully established.

The nominal tower footing resistance in terms of Transmission standard 240-130615862 [7] is indicated in Table 12, and the diameter and d.c. resistance of commonly used earth wires, is given in Table 13.

Table 12: Nominal tower footing resistance (maximum)

Voltage rating [kV]	**Nominal footing resistance** [ohm]
132	20
220	30
275	30
400	40
765	50

Table 13: d.c. resistance of standard Eskom earth wires

Conductor type	**Overall diameter** [mm]	**d.c. resistance at 20˚C** [ohm/km]
3/4.06 mm steel	8.75	3.92
7/3.15 mm (7/.128") steel	9.45	3.55
7/3.35 mm (7/.132") steel	9.54	3.14
7/3.51 mm (7/.138") steel	10.53	2.86
19/2.65 mm (7/.104") steel	13.48	1.88
"105" steel	13.25	1.34
7/2.64 mm Cu	7.92	0.509
OPGW (10 kA)	14.00	0.399
OPGW (16 kA)	17.50	0.220
OPGW (21 kA)	20.00	0.159
Horse ACSR	13.95	0.394
Tiger ACSR	16.52	0.220
Wolf ACSR	18.13	0.183

The nominal footing resistances increase with voltage rating due to back-flashover criteria, and should be regarded as an upper limit. Actual footing resistances can be much lower and tend to decrease with voltage rating, due to the foundation size.

An example of the calculated current distribution of a 15 kA fault on a horizontal 132 kV line with 2 x 7/3.51 mm steel earth wires is shown in Fig 12.

In this example, with typical tower footing resistance and substation earth mat resistance values, the current I_F entering the earth through the faulted tower's footing is less than 13% of the total fault current. This fraction is used for the EPR calculation.

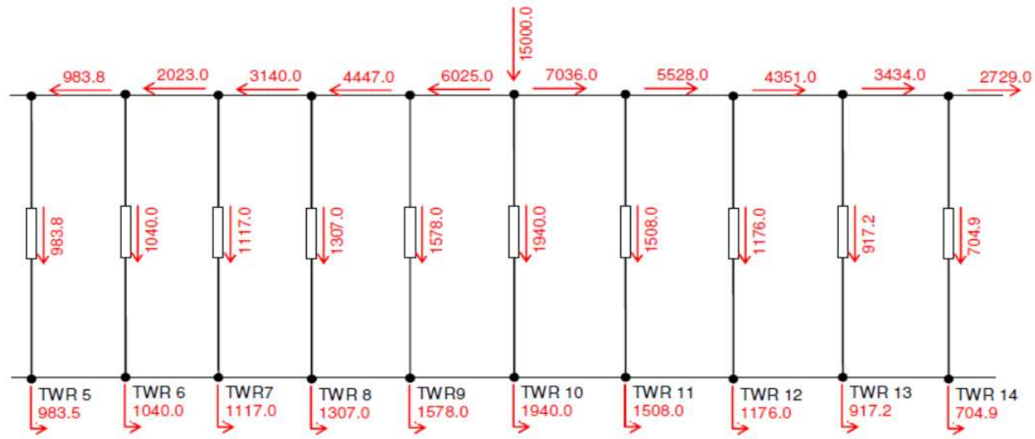


Figure 12: Example of current distribution for a 15 kA fault on the 10th tower of a 132 kV line

c) Currents producing substation EPR

If there is 1- phase to earth fault in or near a substation, the current I_E flowing through the earthing system of the substation causes the EPR. This current is always smaller than the substation's rated fault level, I_d, because a significant portion returns through the earth wires (see Fig 13).

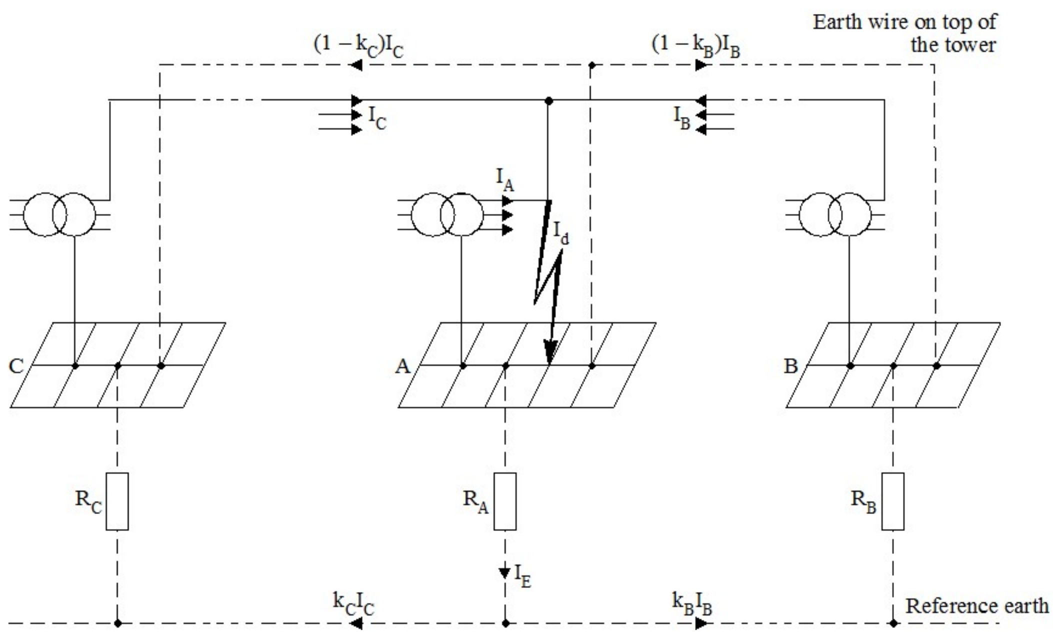


Figure 13: Calculation of electrode current, IE, with a fault inside a substation (from ITU-T Directives, Vol II [30])

There are also two components of I_E, namely the transformer's contribution and the system's contribution. One of them is decisive from the point of view of EPR.

If the earth fault occurs within the substation, the transformer's contribution circulates in the station and never enters the earth, hence only the zero-sequence currents coming from the system outside the station in question can cause EPR.

In this case, the current through the earth (i.e. the current from the network flowing through the earthing resistance R_A of the station) is given by Eqn (14):

$$I_E = \sum_{i=1}^{N} k_i \cdot I_i \qquad [A] \qquad (14)$$

where

N is number of the lines entering the station,

k_i the screening factor of the respective lines (see below), and

I_i the fault current of the line i

If the earth fault occurs outside the substation, the EPR is caused by the zero-sequence current which the station itself feeds into the fault as well as the zero-sequence currents from the system, taking into account the different screening factors (see Fig 14).

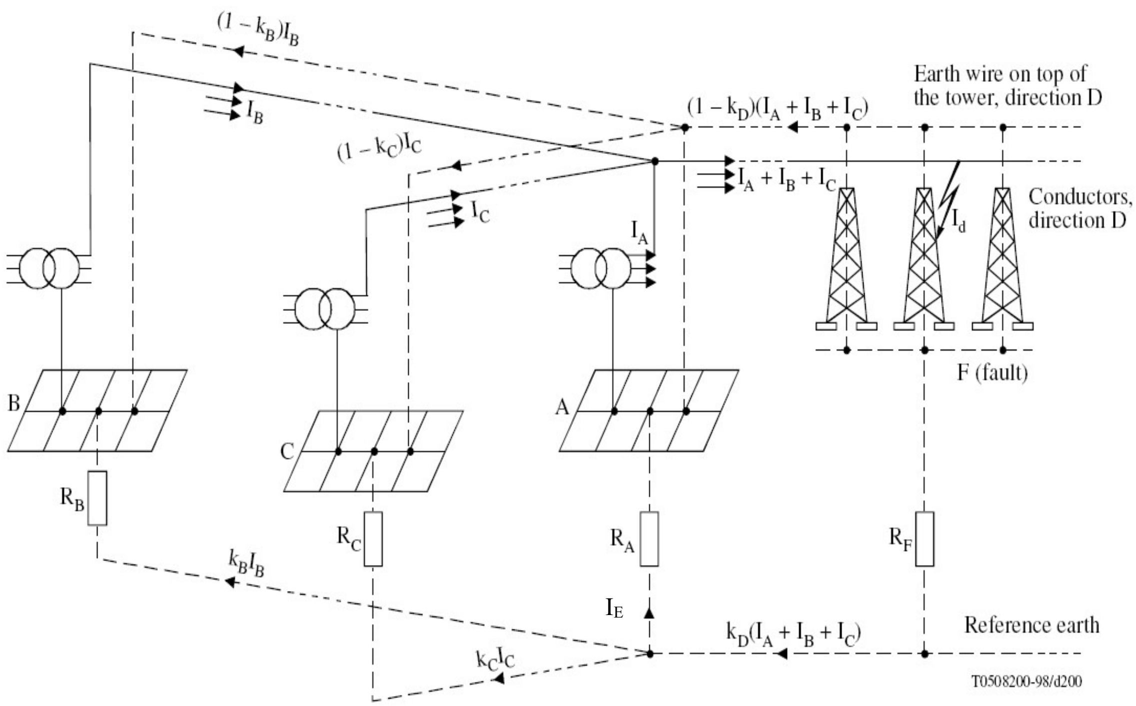


Figure 14: Calculation of electrode current, IE, with a fault outside a substation (from ITU-T Directives, Vol II [30])

If N-1 is number of the lines entering the station excluding the faulted line, the current flowing through the earthing impedance of the station is given by Eqn (15):

$$I_E = k_D \cdot I_A + \sum_{i=1}^{N-1} (k_D - k_i) \cdot I_i \qquad [A] \qquad (15)$$

where

k_D is the screening factor of the faulted line,

k_i is the screening factor of the remaining lines feeding the station,

I_A is the fault current supplied by the substation transformer [A],

I_i is the fault current of the line i [A].

Depending on the amount of current provided by remote stations relative to the current provided by the local transformer, the decisive location of the fault may be either inside the substation or outside. Both situations should be evaluated to determine the worst case EPR at the substation of interest.

In step-down substations, this evaluation should be done on the side of the station transformer which results in the highest fault current. Depending on the transformer rating, this can occur on the lower voltage level.

3.6.3.3 Determination of the most hazardous location(s) of a power system earth fault

a) Conductive coupling only

For conductive coupling, an earth fault at the mast or tower closest to the pipeline will normally produce the highest coating stress, however all masts or towers with a ZOI overlapping the pipeline route need to be considered individually, taking due account of the power line's sliding fault current and the local soil conditions.

b) Inductive coupling only

For inductive coupling, the worst location for an earth fault is usually at one end of the exposure. In Fig 15, a fault at position Y will expose the entire pipeline X-Y to a fault level I_Y, resulting in the highest induced voltage from substation A. The current from substation B will give the highest induced voltage at the fault position X, exposing the entire pipeline to a fault level I_X. Since I_Y is larger than I_X, a fault at position Y will give the worst case.

Should the fault occur between X and Y, the fault level from each side would be higher than I_X and I_Y, however the pipeline is only partially exposed. With both breakers closed, the currents flow in opposite directions and the emfs developed in the pipeline will be 180˚ out of phase, resulting in an overall reduction of the induced voltage.

When the pipeline extends beyond substations A or B, point X or Y will move directly opposite substation A or B and the worst case will result from a fault at substation A or B, respectively.

Breakers at substation A and B will usually not open and auto-reclose at precisely the same instant, and at a given instant following the insulation breakdown, the fault may be fed from substation A only, from substation B only, or from both substations. From an inductive coupling viewpoint, the highest coupling will occur with the fault fed from one (highest) end only. From a conductive coupling viewpoint, the highest EPR around a tower structure will occur with a fault fed from both ends.

For more complex situations, it may be necessary to calculate the pipeline voltage for several possible fault locations, to confirm the worst position.

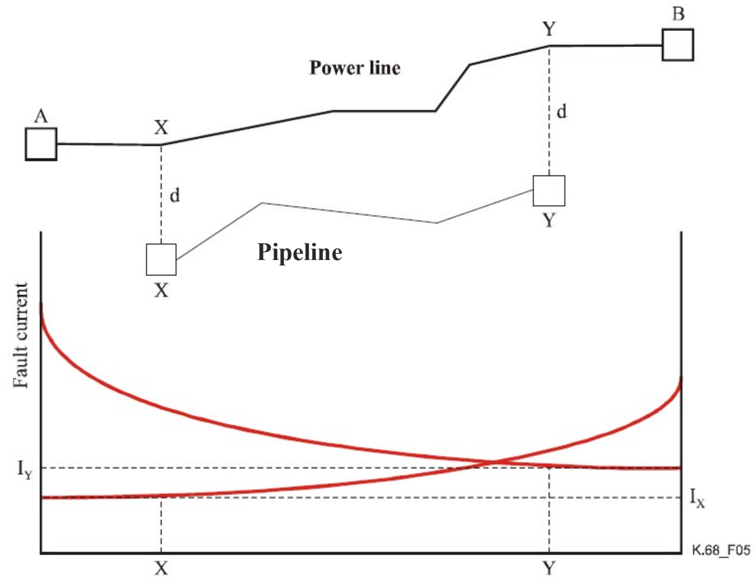


Figure 15: Finding the worst fault position location on arbitrary exposures (adapted from ITU-T Rec K68 [31])

c) Conductive and inductive coupling

For conductive coupling from a power line encroachment that also contains a parallelism, the coating stress is the vector sum of the inductive and conductive coupling effects. The voltage profile produced by inductive coupling must then be established first (see 3.6.6) and considered in combination with the faulted tower's EPR, to determine where the highest pipeline coating stress will occur.

3.6.4 Inducing currents on HVDC power lines

HVDC fault or load currents do not produce any inductive coupling, however, during operational switching transients or when a phase or earth fault occurs, inductive coupling proportional to the current's rate of change can produce considerable pipeline voltages.

The rate of change (dI/dt) is dependent on the impedances inherent to the power line. For HVDC lines of normal construction, the induced transient voltages can be closely approximated by applying a 50 Hz steady state current with a magnitude corresponding to the transient. The d.c. current is replaced by an a.c. waveform with a peak value equal to the d.c. voltage (or Va.c. r.m.s. = 0.707 Vd.c.). The d.c. circuit can be either monopolar (earth return) or bipolar, and the a.c. current should be applied accordingly.

Tests conducted on a pipeline parallel to the Apollo-Pafuri HVDC lines showed that switching transients actually produce higher voltages than earth faults. It was also observed that the duration of switching transient's peak can exceed 0.2 sec, with some ringing occurring even after 1 sec [32].

The permissible touch voltage should therefore be based on an event duration of 1 sec, and the worst condition considered is a switching transient from 0 A to the line's maximum current capacity.

HVDC converters also produce steady state harmonic currents, that can couple inductively with the pipeline. A 6-pulse converter as used at Apollo substation for example, produces a 6^{th}, 12^{th} and 18^{th} current harmonics (300 Hz, 600 Hz and 900 Hz) on the d.c. side. Typically, their magnitude is limited by means of harmonic filters to less than 0.2% of the load current, and the resulting pipeline voltages do not pose any significant safety hazards.

3.6.5 Pipeline coating resistivity

The variation in coating resistivity, thickness and specific resistance of commonly used pipeline coatings is indicated in Table 14 :

Table 14: Typical variation of coating resistivity and thickness

Coating material	**Laboratory resistivity** [ohm.m]	**Field resistivity, minimum** [ohm.m]	**Field resistivity, maximum** [ohm.m]	**Coating thickness** [mm]	**Specific resistance** [ohm.m²]
Bitumen	> 10^{12}	0.2×10^6	2×10^6	4 – 10	$0.8 \times 10^3 - 20 \times 10^3$
Polymer-modified bitumen (e.g. Bituguard®)	10^8	4×10^6	8×10^6	4 – 5	$16 \times 10^3 - 40 \times 10^3$
Polyethylene (e.g. 3LPE, MDPE)	10^{16}	20×10^6	200×10^6	0.8 – 4.0	$16 \times 10^3 - 0.8 \times 10^6$
Fusion-bonded epoxy (FBE)	10^{13}	2×10^6	20×10^6	0.3 – 0.5	$0.6 \times 10^3 - 10 \times 10^3$
Polyurethane (rigid PU, 2-component PU)	10^{14}	20×10^6	200×10^6	0.4 – 3.0	$8 \times 10^3 - 0.6 \times 10^6$

Resistivities of coatings in field conditions are considerably lower than the same material under laboratory conditions, due to defects or holidays in the coatings, poorly coated fittings, defects in the coating of the field joints and moisture absorption. For standard bitumen coatings in particular, the resistivity tends to decrease over time.

Pipelines with low resistivity coatings will exhibit lower induced voltages than pipelines with high resistivity coatings (see 3.6.9). For calculations related to safety and a.c. induced corrosion, the highest expected resistivity value should be applied. For d.c. leakage calculations however, the lowest expected value should be used, since the cathodic protection current increases with decreasing resistivity.

3.6.6 Calculation of inductive coupling during a power system earth fault

With the worst fault location(s) established according to 3.6.3.3 and the corresponding fault current according to 3.6.3.2, the fault current can be applied to the phase conductor positioned closest to the pipeline. Normal load currents in the non-faulted phases and in any adjacent power lines may be ignored, in view of the much larger zero-sequence current produced by the faulted phase.

The next step is to calculate the current induced in the earth wires during the fault. Following this, and after data entry of the respective pipeline and power line routes, pipeline coating and soil characteristics, the emf induced in the pipeline sections may be calculated. To ensure that the effect of the power line catenary is accounted for, section lengths should not exceed 50 m.

The pipeline voltage profile and shunt and series current are calculated next from these discrete section emfs and any specified earthing points or any discontinuities on the pipeline (e.g. insulating flanges). At this stage it is also possible to experiment with different earthing points as a means of mitigation, if the coating stress limit or the safety limit is exceeded (see 3.6.9, 3.6.11).

3.6.7 Calculation of conductive coupling from towers and substation earthing grids

3.6.7.1 Calculation of the EPR or surface potential

In homogenous soil, the EPR of the soil around a faulted tower or substation decreases as the inverse of the distance from the centre of the equivalent hemispherical electrode. This simple relationship does however not apply for stratified soil, which can cause order of magnitude EPR increases or decreases at a distance from the point of current injection. In particular, when the soil is comprised of a low resistivity upper layer over high resistivity bedrock, the current is confined to the upper layer and the EPR may spread over a much greater distance.

To model the faulted tower footing or earthing grid in multilayer soil, a wire or grid model is required. For substation grids, a suitable model is a rectangular meshed grid of roughly the same size as the actual substation, consisting of 10 mm diameter copper conductors, buried at a depth of 1 m.

In low or medium resistivity soil, the grid model needs to have no more than about 10 conductors in total, e.g. a 200 m x 200 m grid can be modelled with sufficient accuracy by a mesh size of 50 m x 50 m, even though the actual conductor density would be higher. Additional conductors will not reduce the grid's effective resistance to earth or affect the EPR profile outside the station but will increase computation time.

In high resistivity soil (> 1000 ohm.m) the conductor density should be increased until there is no further decrease in the grid's effective resistance to earth.

Modelling tower footings can be more complex due to the variance of foundation designs, which are adapted to suit the mechanical properties of the local soil. Acceptable accuracy will however result from approximate models. For lattice-type self-supporting EHV towers with concrete-encased footings, a suitable model would consist of four interconnected rod electrodes, each of 1.5 m diameter and 5 m depth, spaced according to the tower's base dimensions.

For guyed towers, the anchors and mast support foundations may be similarly modelled, and the model may be scaled down for smaller HV towers. Metallic or reinforced concrete pole-type tower footings may be modelled as a single rod electrode, with dimensions in accordance with the actual footing and concrete foundation diameter.

When there are counterpoises installed, these will have a significant effect and they should be modelled according to their actual dimensions.

Some software packages will permit the modelling of the concrete around the footings, however, being relatively conductive, the concrete may as a first approximation be regarded as being part of the metallic structure. More accurate modelling of the foundations (pads, piles etc.) will also have only a limited influence on the calculated EPR around the tower.

As discussed in 3.6.3.2, only a fraction of the fault current will enter the earth at the tower footing. Once this fraction is determined, the grid or tower model is entered and soil layers specified, it is possible to compute the potential rise of the footing and the EPR as a function of distance from the tower or grid to the pipeline.

A useful check is that the potential rise should not exceed 5 kV for substation grids or 30 kV for tower footings. Substation grids will only rarely exceed 5 kV, and only in the case of smaller HV substations in poor soils; for Eskom's EHV substation grids 5 kV is the design limit. In the case of towers equipped with earth wires, a potential of the faulted tower greater than 30 kV is highly unlikely.

3.6.7.2 Calculation of pipeline touch voltage

For a pipeline traversing an EPR zone, some of the potential will be transferred to the pipeline through its coating. Some of this transferred potential can appear on the pipeline well beyond the shared servitude. The pipeline touch voltage (which, for practical purposes, is equal to the coating stress) is then the difference between the local EPR and the voltage transferred to the pipeline (see Fig 16).

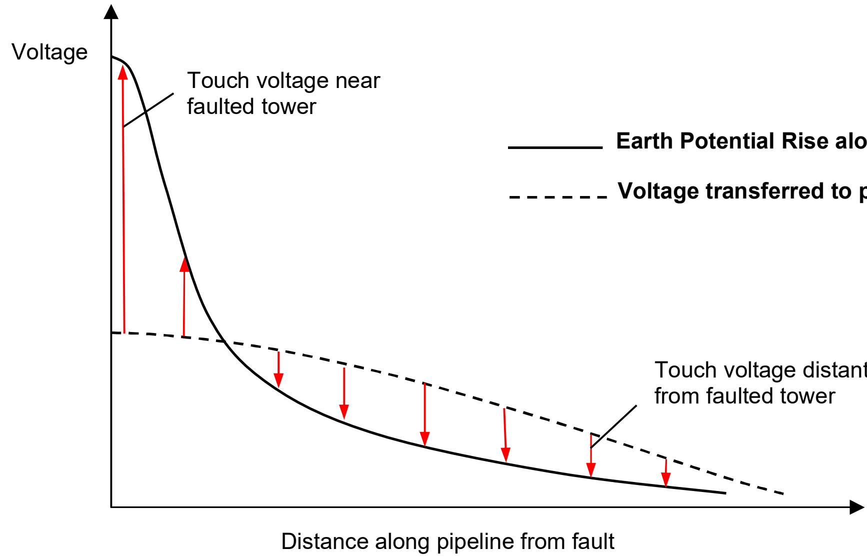


Figure 16: Touch voltage resulting from conductive coupling from a faulted tower

To calculate the voltage transferred to the pipeline requires the model to extend to a point where the EPR has effectively diminished, which can be several kilometre. At the ends of this length, an earth point is required to represent the remainder of the pipeline's coating admittance to earth. A further uncoated 500 m section of pipeline may be specified to provide such an earth.

If the exposure involves a parallel or quasi-parallel section, the total pipeline touch voltage must take both inductive and conductive coupling into account. This may be achieved by summation of magnitudes of the pipeline voltage profile due to induction and the pipeline touch voltage due to conductive coupling.

This worst-case summation closely represents the actual situation, since the induced pipeline voltage is usually almost in phase with the influence of the EPR. The effects must therefore be added and will produce more severe touch voltages and coating stresses in combination.

3.6.8 Calculation of pipeline voltages during normal and emergency load conditions

Compared to fault conditions, the emf produced by a power line carrying a balanced load current is much more sensitive to the precise juxtaposition of the phase conductors with respect to the pipeline – under a tower with a horizontal layout for example, the emf is near zero underneath the central conductor but reaches a maximum underneath the outer conductors.

It is therefore important that the actual position of the phases is accurately represented for the normal and emergency load calculations. These are dependent on the tower configuration, the conductor catenary and transpositions.

If there are multiple circuits or multiple power lines in the servitude, the respective phasing of the conductors must be considered, as discussed in 3.6.3.1 g).

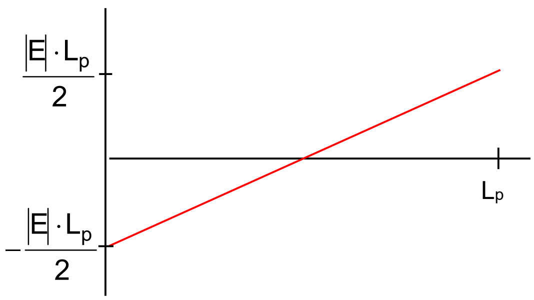
There is no conducted component present as in the case of fault conditions.

The calculation of the pipeline voltage profile is otherwise very similar to 3.6.7, and earthing points can be applied to the pipeline to ensure that the safety limit is met during emergency load conditions and the a.c. corrosion limit is met during normal load conditions.

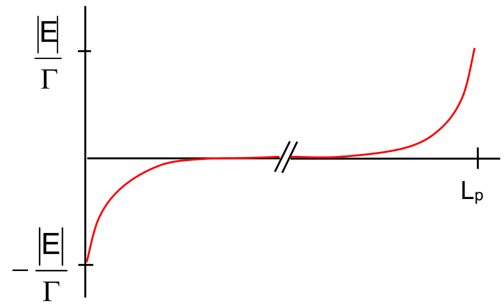
At peaks in the voltage profile, the safety limit may be exceeded - provided further measures are taken to equalize the potential of the local soil to ensure that the touch and step limits are not exceeded (e.g. by means of gradient mats or gradient wire).

3.6.9 Determination of the most likely locations of pipeline voltage peaks

For a short, parallel exposure with uniform soil conditions and no earths, the voltage developed on the pipeline due to inductive coupling will have a linear profile with maxima at the pipeline ends and a zero crossing in the centre, as shown in Fig 17 (a). For a similarly uniform, but long exposure, the pipeline will become more lossy, and the linear profile will be replaced by an exponential decay, Fig 17 (b).



(a) Electrically short pipeline ($L_p < 1/\Gamma$)



(b) Electrically long pipeline ($L_p > 1/\Gamma$)

Figure 17: Voltage developed on uniformly exposed pipelines with no earthing

The distinction between long and short exposures is made based on the electrical length of the pipeline, $1 / \Gamma$, where the parameter Γ is the pipeline's propagation constant (m^{-1}). For a given inducing field strength E (V/m), the pipeline voltage magnitude will not increase beyond the value $|E| / \Gamma$, irrespective of any further increase in exposure length.

The electrical length $1/ \Gamma$ is a function of the pipeline's depth, wall and coating properties, diameter, the soil resistivity and the frequency. Typical values for 50 Hz range from 1 km to 5 km for pipelines with bitumous coatings, and from 10 km to 30 km for pipelines with epoxy, polyethylene or polyurethane coatings.

As a result, the voltages developed on long pipelines with modern, high resistivity coatings can be around *ten times higher* than on pipelines with bitumous coatings, and the width of the voltage peak is increased by the same order.

For both short and long lines with uniform exposures, the most effective mitigation earthing will be at the pipeline ends, i.e. at the peaks of the voltage profile.

For long, non-uniform exposures, voltage peaks are likely to develop in addition at any discontinuities in the exposure, for example at power line or pipeline route deviations, at crossings or power line transpositions (under steady-state conditions only) and at insulating flanges (see Fig 18).

These voltage peaks will exhibit the same exponential decay on either side of the discontinuity as indicated in Fig 17(b) and will again not exceed the value $|E| / \Gamma$ in magnitude (E in this case being the maximum inducing field strength applicable to the section in question).

The most effective mitigation earthing is usually at the location of these voltage peaks. When earthing is applied at a given point on a pipeline however, the voltage can increase or "balloon" at another point, and for this reason additional earthing points may also be required in the uniform sections of the exposure, as will be evident from the calculated voltage profile.

Even with mitigation earthing applied to bring the pipeline voltages within limits safe limits, cutting a pipe or disconnecting a pipe joint would immediately introduce a new voltage peak location. The voltages on opposite sides of the cut or open joint will be 180° out of phase, resulting in a voltage difference equal to the sum of the induced voltage on each side. This can be extremely dangerous, and a temporary bonding link must always be installed across the section where the cut or section removal is going to take place, on pipelines subject to inductive coupling from power lines (see 3.7.1.14).

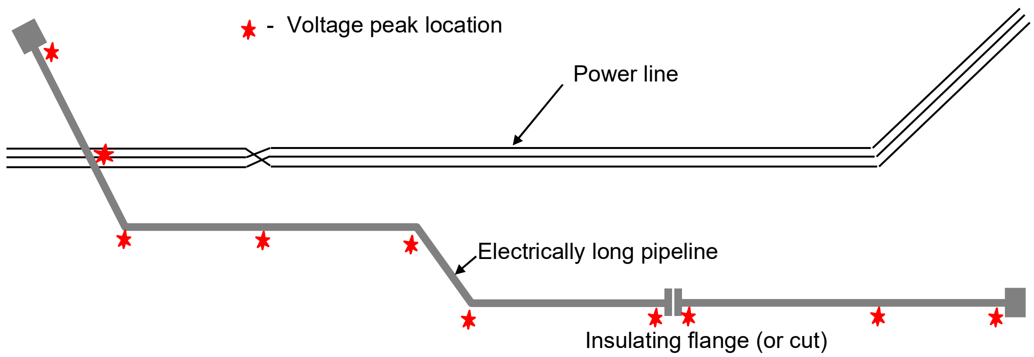


Figure 18: Location of voltage peaks on non-uniform exposure pipeline with no earthing

3.6.10 Calculation of d.c. leakage from pipelines and anode ground beds

The surface potential distribution adjacent to a pipeline may be calculated for homogenous soil from Eqn (9) as a function of protection current density.

In case of stratified soil, a computer simulation is required. A substantial section of the pipeline should be modelled (e.g. 5 km) to ensure that the field distribution remains cylindrical up to the distance considered. The pipeline should be energised to -2.0 V d.c. With an a.c. computer model, the frequency should be adjusted to 1 Hz or less, to simulate d.c. conditions.

If the resulting surface potential difference between the towers of any span exceeds 400 mV, the 200 mV positive d.c. potential shift limit could be exceeded, and the earth wires of the tower closest to the pipeline have to be insulated.

Anode ground beds produce cathodic interference at the nearest tower(s) and anodic interference at the towers where the injected current returns to earth, as shown in Fig 19:

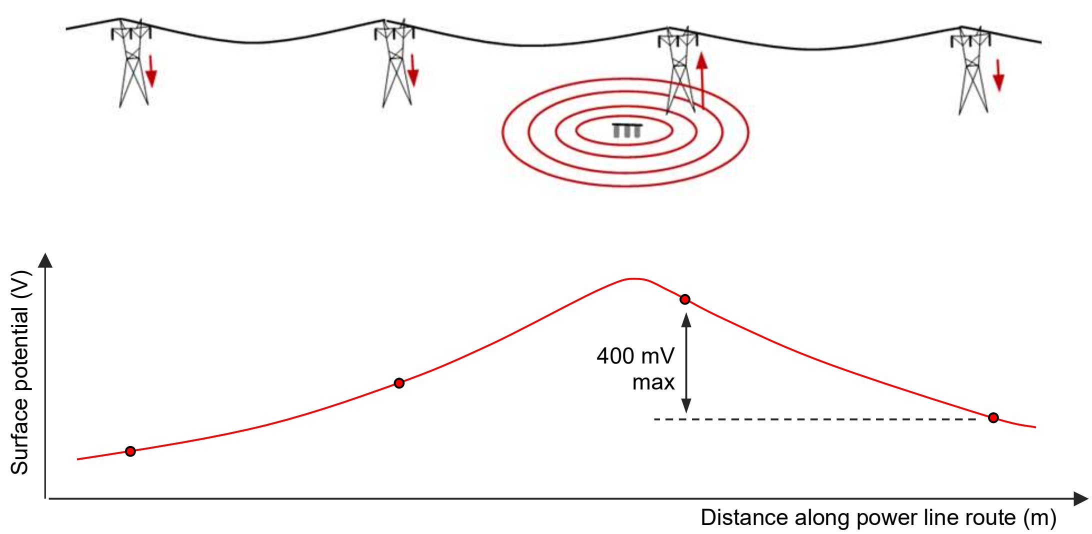


Figure 19: Surface potential gradients and leakage currents from an anode ground bed

The anode should be modelled according to its actual dimensions and energised to the rated capacity of the CP rectifier (typically 100 V, 50 A). If the resulting potential difference between two towers of a span exceeds 400 mV, the anode should be moved further from the power line, or the tower's earth wires successively insulated until the potential difference between the remaining towers drops below this value.

If the anode is very close to a tower with an insulated earth wire, the profile must be examined to ensure that the potential difference across the tower legs or guy anchors is less than 400 mV. If this value is exceeded and the anode cannot be moved, sacrificial anodes are required on the legs furthest from the anode. Post-installation d.c. shift measurements are then required at the tower footings, in order to correctly size the sacrificial anodes (see 3.3.8 (b)).

3.6.11 Calculation of pipeline voltages with mitigation measures applied

The calculation of pipeline voltages due to inductive coupling with mitigation earthing applied is similar to the calculation without earths, as discussed in 3.6.6 and 3.6.8, but with all the earthing points and insulating flanges included in the circuit. The applied earths should include zinc ribbons, earth rods, pump station earthing mats and other earths connected to the pipeline through d.c. decouplers but should exclude the valve station gradient mats which are connected to the pipeline through SPDs, unless the calculated voltage profile indicates that the SPD's breakdown voltage is exceeded at any specific valve station, as is likely to occur during fault conditions.

In most software packages, this calculation will only provide the resultant pipeline voltage with respect to remote earth. The touch voltages will be further reduced by gradient mats at valve chambers, and both the touch voltage and the coating stress will be further reduced along pipeline sections with gradient wire(s).

Properly designed and installed gradient mats around valve chambers will invariably bring the step and touch voltages at the chamber to within the required limits, and further simulation of this situation is generally not required. If no external mat is used and only the chamber's re-bar is earthed, it may be necessary to model this situation specifically.

The effect of the gradient wire also needs to be investigated with a suitable simulation. For example, Fig 20 shows the result of CDEGS simulation of short (150 m) sections of Type II zinc ribbon, installed next to a 1100 mm diameter pipeline with a bitumen coating, in soil consisting of a 15 m thick layer of 500 ohm.m over 1500 ohm.m bedrock. The pipeline is energized to 100 V.

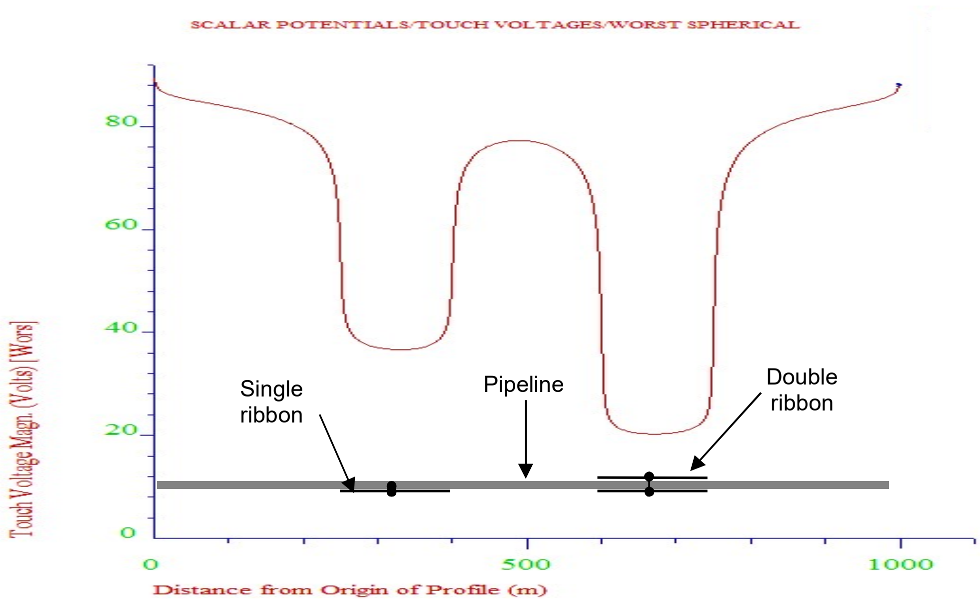


Figure 20: Example of the reduction of touch voltages by zinc ribbon installed in pipeline trench

In this example, a single and double ribbon is seen to reduce the touch voltage by more than 60% and 80% respectively. Generally, this effectiveness decreases with increasing soil resistivity, but it is also sensitive to soil stratification. Each specific situation must therefore be confirmed with a similar calculation.

In the case of conducted coupling, a zinc ribbon section opposite tower footings will also be effective in reducing the touch voltages where there are sharp EPR gradients present – however, the ribbon can have the undesirable effect that the potential transferred to the pipeline as discussed in 3.6.7.2 increases substantially, creating hazardous touch voltages remote from the fault location, as shown in Fig 21.

Because of this effect, it is not always advisable to install zinc ribbon near towers or substation grids - though this may be unavoidable if the coating stress limit is also exceeded. If only the safety limit is exceeded, gradient mats may be used for mitigation in these areas. When zinc ribbon is used, the resultant touch voltage away from the tower or grid must in any event always be evaluated by means of an appropriate simulation model.

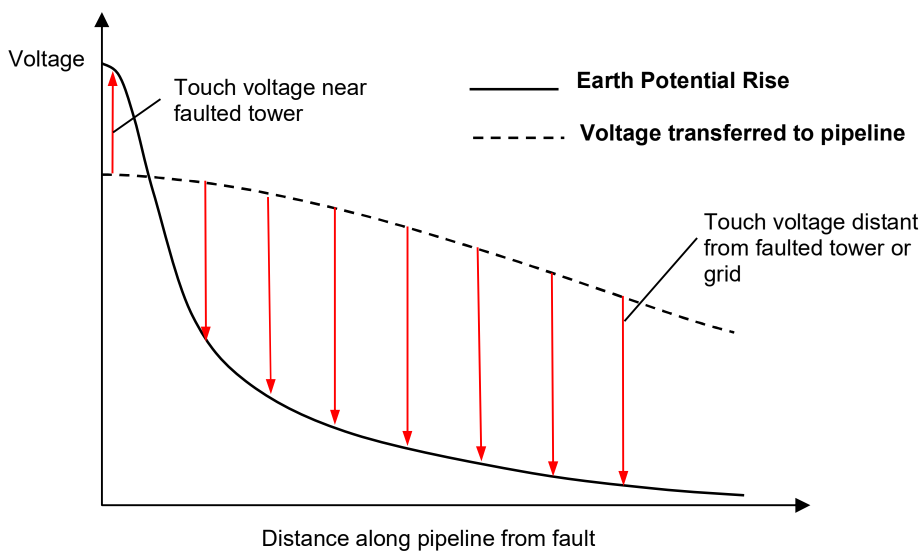


Figure 21: Touch voltage resulting from conductive coupling from a faulted tower, with zinc ribbon installed near the faulted tower or grid (compare to fig 16)

3.6.12 Determination of current rating of d.c. decoupling devices, VLDs and cables

Included in the coupling simulation results for both emergency load and fault conditions will be the individual currents flowing to earth at each earthing point, as well as the series current along the length of the pipeline. These current levels have to be compared against the VLD and d.c. decoupler device ratings, e.g. the maximum continuous a.c. rating and the fault rating specified in B.2 and B.4 of Annex B. This also applies to d.c. decouplers installed across insulating flanges, which will carry the full series current at the respective point on the pipeline.

If the predicted current levels are higher than the rated values, the device ratings must be increased, or the earthing resistance of the individual mitigation earthing point has to be reduced (e.g. by splitting the length of the zinc ribbon section in two). If increased device ratings are used, the cable cross-section specification B.5 of Annex B must be increased accordingly.

3.7 Mitigation measures

3.7.1 Mitigation measures applicable to pipelines

3.7.1.1 Routing of the pipeline

If the permitted coupling levels are exceeded, increasing the separation between the power line and pipeline may in some cases be a viable option to reduce coupling to acceptable levels.

Increasing separation is especially suitable for conductive coupling from power line towers, substations and transformers, where a reasonable increase in separation can overcome most problems.

Substantial re-routing is usually required to reduce inductive coupling because of the slow decrease with distance and is often not a practical solution.

3.7.1.2 Gradient control wires / ribbons

Gradient control wires provide a.c. mitigation by two mechanisms - firstly, by providing an earthing point which reduces the overall pipeline voltage, and secondly, by changing the potential of the soil around the pipeline, thereby reducing the coating stress and touch voltages.

They are most effective in conditions of low resistivity soil overlaying high resistivity bedrock, and least effective in high resistivity soil overlaying low resistivity soil.

Gradient control wires typically consist of a specified length of one or two bare, profiled zinc conductors (also referred to as zinc “ribbons”) installed in the corner(s) of a pipeline trench, prior to bedding and backfill material. A suitable specification for zinc ribbon is provided in B.1, Annex B.

If the pipeline is protected with an ICCP system, they must be connected to the pipeline through appropriately rated d.c. decouplers. The d.c. decouplers are normally installed above ground, housed in suitably designed a.c. mitigation stations.

For pipelines without ICCP systems, the zinc ribbon may be connected directly to the pipeline, at regular intervals (nominally 300 m). In this case they will behave as sacrificial anodes and provide cathodic protection to the pipeline, in addition to providing a.c. mitigation.

The connections between the ribbon, the d.c. decoupler and the pipeline must be made with copper or aluminium wire as specified in B.5, Annex B.

The earthing resistance is determined primarily by the resistivity of the layer in which the ribbon is installed, and is calculated from Eqn (16):

$$R = \frac{\rho}{2\pi\ell} \cdot \ln\left(\frac{\ell^2}{sd}\right) \quad \text{[ohm]} \qquad (16)$$

where:

- ρ is the soil resistivity [ohm.m],
- λ is the length of the ribbon [m],
- s is the burial depth [m],
- d is the average thickness or the diameter [m].

Eqn (16) ignores the self-resistance of the wires; this limits its application to lengths to approximately 500 m for type II zinc ribbon (see Annex B). The resulting earthing resistance for some typical conditions is shown in Table 15.

Table 15: Earthing resistance provided by gradient control wire, buried 2 m deep

Electrode type (Type II Zinc)	$R_{electrode}$ for soil resistivity [ohm]		
	100 ohm.m	**250 ohm.m**	**500 ohm.m**
100 m zinc ribbon	2.1	5.4	10.8
200 m zinc ribbon	1.1	2.7	5.4
300 m zinc ribbon	0.8	1.9	3.8
400 m zinc ribbon	0.6	1.5	3.0

To limit both the current rating requirement of the d.c. decouplers and the voltage gradient along the ribbon's length resulting from its self-impedance, ribbon sections should generally not exceed 400 m in length. For optimum current distribution the d.c. decouplers should be connected near the centre and successive sections should not be in direct contact.

In an alternate approach, zinc ribbons are made continuous and are connected to the pipeline with d.c. decouplers at regular intervals (≤ 400 m). Whilst in this configuration the ribbon could be less effective as earth electrode (requiring longer overall lengths), it does provide alternate current discharge paths should a decoupler become inoperative.

The earthing resistance of zinc ribbon improves only very marginally by using two ribbons as opposed to one. Using two ribbons is only necessary when the coating stress is very high, in which case a second ribbon can provide some improvement (see Fig 20).

3.7.1.3 Vertical earth rods

Like gradient control wires, vertical earth rods can be used to provide an earthing point and thereby reduce the pipeline voltage, but they are not as effective in changing the potential of the earth around the pipeline.

They find application mainly when the resistivity of the upper soil levels is very high compared to the lower levels, when gradient control wires are least effective. They can also be used in combination with gradient control wires, i.e. by connecting one or more vertical rods to the horizontal ribbon, thereby providing access to the low resistivity layers.

Vertical earth rods for this purpose require a borehole to be drilled into the conductive layers and can exceed 100 m in depth. To prevent wall collapse, a steel pipe sleeve is normally inserted, typically of 200 mm - 300 mm diameter. The earth rod may be implemented with Type II zinc ribbon, fitted centrally in the sleeve which is then filled with carbonaceous backfill. This arrangement improves durability and increases the effective contact surface.

For homogenous soil, the earthing resistance of a vertical earth rod is given by Eqn (17):

$$R = \frac{\rho}{2\pi\ell} \cdot \ln\left(\frac{4\ell}{d}\right) \quad \text{[ohm]} \qquad (17)$$

where:

- ρ is the soil resistivity [ohm.m],
- λ is the length of the rod [m],
- d is the diameter of the steel sleeving [m].

For stratified soil, the earthing resistance can be calculated using suitable software. The actual resistance can also be measured during the drilling process, to determine if the low value required has been achieved and if further drilling is warranted.

Connection to the pipeline is done in the same manner as gradient control wires, i.e. through a d.c. decoupler in the case of pipelines equipped with ICCP systems or with a direct connection otherwise, using stranded wire as specified in B.5, Annex B.

3.7.1.4 Gradient control grids

Gradient control grids or mats can be used at exposed appurtenances of buried pipelines (i.e. valve chambers, pigging stations, CP stations etc. but excluding test posts, see 3.7.1.7) to equalise the soil potential around (or inside) the appurtenance to the pipe potential, thereby reducing the touch and step potentials.

Gradient control grids typically consist of a wire mesh or spiral at a depth of about 0.3 m installed around the appurtenance to a distance of at least 1.2 m, so that a person in contact with the appurtenance or enclosure will always be standing over the mat.

Both spiral and wire mesh type gradient control grids provide very effective touch and step potential mitigation at 50 Hz. Mesh type grids are however the preferred type, because they allow more effective dissipation of current during surges (e.g. from switching and from lightning).

In the case of valve chambers constructed with steel reinforcing in the floor and/or walls, the reinforcing can be used for gradient control inside the chamber, by forming a Faraday cage at pipeline potential. This effectively reduces the internal touch and step potentials to zero for 50 Hz and to very low values for surges.

If the enclosure is non-metallic and has no external metallic components (e.g. lids, ladders, etc.) within reach of a person standing next to the enclosure, the external grids are not required for touch voltage mitigation – provided the step voltages are within the limits of table 1.

The connection to the pipeline is normally made through a voltage limiting device or VLD (see 3.7.1.5), and the grid remains out of circuit under normal operating conditions. The cabling comprises stranded copper or aluminium wire as specified in B.5, Annex B. When there is a distinct possibility of vandalism, the connection should be made using a temporary jumper (see 3.7.1.6 and B.6, Annex B).

The efficiency of a gradient control grid as an earthing point is usually quite low, although the cumulative effect of several grids can be of some benefit during fault conditions. In homogenous soil, the earthing resistance of a gradient control grid is given by Eqn (18):

$$R = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \quad \text{[ohm]} \qquad (18)$$

where:

- ρ is the soil resistivity [ohm.m],
- A is the area of the grid [m²].

A specification for a wire mesh type gradient control grid is given in B.3, Annex B.

3.7.1.5 Solid state d.c. decouplers and voltage limiting devices (VLDs)

Any direct earthing applied to the pipeline will burden the CP system, and d.c. decouplers are normally required which provide d.c. isolation (up to a given threshold) whilst exhibiting a very low a.c. impedance.

D.c. decouplers are designed with multiple parallel paths to accommodate the normal a.c. current, fault current and lightning surges respectively. These devices are required when mitigation earthing must be functional during steady state conditions on the power line (e.g. vertical rods or gradient control wires) whilst blocking the flow of d.c. current.

To prevent excessive d.c. voltages, d.c. decouplers will also conduct direct current when the device's blocking voltage is exceeded. This can occur when there are sources of stray d.c. in the vicinity. Normally the d.c. blocking voltage is asymmetric (-3 V /+1 V) to accommodate the negative operational voltage of the pipeline.

If the pipeline is influenced by d.c. traction, the negative clamping limit should be adjusted (e.g. to -12 V /+1 V), to prevent frequent loading of the CP system during negative voltage excursions. A suitable specification is provided in B.2, Annex B.

Similar d.c. decouplers are required to provide a low impedance a.c. path across insulating flanges, however if both sides are cathodically protected, the voltage should be symmetric (-2 V /+2 V). This permits 2 V blocking when the CP on either side is switched off. In case one side is always earthed, for example at a pump station, an asymmetrical unit is used.

For gradient control mats at valve chambers, an a.c. path is not required during steady state conditions. In this case a voltage limiting device is used that is functional only during transients due to a.c. faults or lightning. A VLD (e.g. a GDT or a MOV) with an a.c. clamping voltage around 75 V r.m.s. is suitable for this purpose. A specification for this type of device is provided in B.4, Annex B.

3.7.1.6 Vandal-proofing of valve chambers with gradient control grids

The rampant vandalism experienced by some local pipeline operators in recent years is a strong incentive for not having any components with scrap value inside valve chambers, including protective devices and wiring. The resulting risk of electrical shock should then be minimised by applying the following measures:

i) Use of a temporary cable (e.g. a car battery jumper lead with insulated handles) when entering a valve chamber, in lieu of a VLD. The pipeline and the gradient control grid must be equipped with suitable connection points for cable attachment, and there must a clearly visible, plastic warning sign to warn of dangerous voltages inside the chamber without such a cable.

ii) Use of insulating coatings to cover all exposed metallic parts connected to the pipeline – for example paint of high dielectric strength (e.g. acrylic/epoxy/enamel/urethane/silicone/parylene), mastic tape or composite shrouds.

A specification for valve chambers at risk of vandalism is provided in B.6, Annex B.

The tendency by affected pipeline operators is also to replace metallic lids and lid seats with non-metallic types, and to no longer equip chambers with steps or ladders but for maintenance staff to use their own extendable ladders. To prevent unwanted step and touch scenarios, these ladders should be non-metallic, as commonly used in the electrical industry.

It should be noted that these are stop-gap measures to be applied only as long as the vandalism situation persists, and that permanent cabling with VLDs remains the preferred method for connecting the gradient control grids to the pipeline.

3.7.1.7 Test posts with a.c. and d.c. coupons or probes

Test posts (TPs) are normally installed as part of CP systems, typically at intervals of about 1 km. TPs contain the terminals of cables connected directly to the pipe and (sometimes) to a stationary reference electrode, to facilitate pipe-to-soil potential monitoring. Portable devices can be used if no stationary reference electrodes are installed.

For a.c. potential measurements, reference electrodes (portable or stationary) must be located at “remote earth”, i.e. at a sufficient distance from the pipeline to prevent measurement errors due to the IR voltage drop in the soil. Dependent on pipe diameter, coating and local soil conditions, this distance can be several meters, and may be determined using the iterative method described in Annex G of ISO18086 [23].

TPs are also used for housing recording equipment during 24 h or 48 h potential surveys. Typical enclosures include pre-cast concrete bunkers with steel doors, and galvanized steel cabinets installed on a pre-cast concrete base. Vandalism is a major concern, and to help act as a deterrent, the use of aluminium or other theft-resistant cabling is recommended in place of copper. Some local petrochemical companies use concrete posts, either with a small lockable enclosure on top (“mushroom” type) or with access only for banana plugs (“post” type) - these types are relatively inconspicuous and have been less subject to vandalism.

For pipeline sections that are subject to steady state a.c. induction, it is essential that the TPs are also equipped with a.c. coupons or probes, which enable current density measurements for comparison against the a.c.- induced corrosion limits (see 3.3.7).

The location of coupon- or probe-equipped TPs should be carefully selected based on the a.c. corrosion risk, and should include:

- areas with low soil resistivity,
- areas with high a.c. interference levels,
- areas where a.c. corrosion has been experienced,
- areas with d.c. interference, e.g. near d.c. railways or foreign c.p. systems,
- areas with high applied d.c. levels (where overprotection is possible),
- inside casings with low resistivity fillers (e.g. bentonite).

Coupons are used simulate a coating defect and are installed next to, in the same bedding material and operated at the same potential as the pipeline, to ensure that the chemical reactions at the pipe-to-soil interface are accurately replicated. The measured pipe-to-coupon current can be readily converted to current density. This density generally increases with smaller defects, and as a result a.c. corrosion is most often observed at small defects on pipelines with high quality coatings. The size of a.c. coupon's exposed steel area in contact with the soil has been standardized at 1 cm^2.

For d.c. coupons used for CP purposes, the exposed area can range from 1 cm^2 to 100 cm^2 and must be selected to reflect the size of the coating defects expected, which varies with pipe size and coating type. If d.c. coupons are too small, this can significantly over-estimate the protective current density of larger defects, resulting in inadequate cathodic protection [34].

For the application of the limits (see 3.3.7) however, both the a.c. and d.c. current density should be measured on the same 1 cm^2 coupon.

ER or electrical resistance probes offer an alternative to conventional coupons. ER probes contain one exposed and one protected resistive element and the difference in resistance can be converted to metal loss, thereby providing a direct measurement of the corrosion rate. ER probes can also be used to monitor the a.c. and d.c. current density.

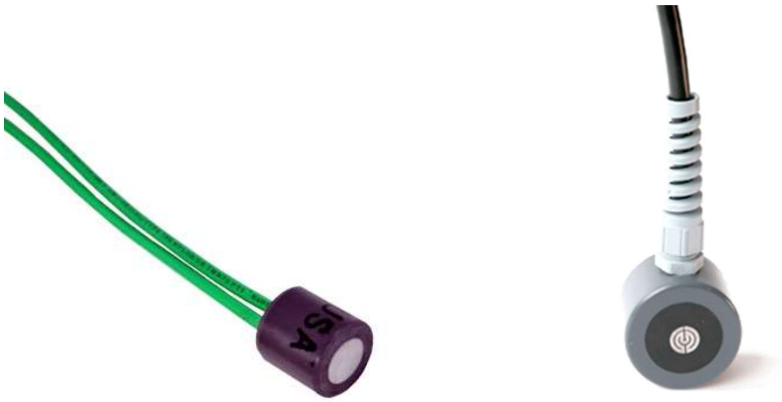


Figure 22: Regular steel coupon (L), ER probe (R), both 1 cm^2

TPs may require gradient control mats for protection from excessive touch voltages during power line faults. If these mats are connected to the pipeline with a solid conductor or a d.c. decoupler, any induced steady state a.c. potential will produce a gradient field in the soil, and coupons or probes located inside this field will under-estimate the a.c. current density. Locating the a.c. coupon or probe at a distance of at least 5x the maximum dimension of the mat will prevent measurement errors. This precaution also applies to a.c. coupons or probes in the vicinity of any other metallic structure connected to the pipeline (for example sacrificial anodes).

Gradient control mats connected to the pipeline with a VLD will experience no current flow or gradient field during steady state a.c. conditions, and then this precaution is not required.

TPs equipped instead with a stone or asphalt ground cover around the base or constructed with a "dead-front" arrangement as per NACE SP0177 [25], eliminate the need for a gradient control mat.

Gradient control mats directly connected to the pipeline can also affect d.c. coupon or probe readings, and the same minimum separation should be applied as for a.c. coupons or probes, as indicated above. When the connection is through either a VLD or a d.c. decoupler, d.c. coupons or probes may be located near or underneath gradient control mats at normal distances (>1 m).

Following installation of the TPs and commissioning of the CP system, sufficient time must be allowed for polarization and the settlement of a.c. spread resistances at coating defects (the latter typically taking several weeks to months). Only then can verification measurements be made to ensure that the average a.c. and d.c. current density and the pipe a.c. potential are within design limits. This is an essential part of the overall a.c. mitigation design, as, due to several unpredictable variables (see 3.3.7), a desktop design by itself is not a guarantee that the current density limits will be met.

After this initial verification, periodic measurements must be made to ensure that the limits are maintained, at intervals not exceeding 3 years and additionally when there is any change in the CP system or load upgrade on the inducing power line(s).

Further information covering the selection, installation and verification measurements using coupons and probes is provided in ISO 18086 [23] and ISO 22426 [34].

3.7.1.8 Bonding with existing structures, d.c. railways and other pipelines

When a new pipeline subject to a.c. coupling is installed next to an existing pipeline, and if there is any possibility of a person being in simultaneous contact with both, the two pipelines must be cross bonded with bonding links at intervals not exceeding 1 000 m, to prevent any hazardous potential differences. These can be direct bonds, resistive bonds or d.c. decouplers, as dictated by the CP requirements.

At crossings or close approaches with d.c. railways, pipelines should be bonded to the rails with a directional drainage bond in accordance with SANS 50162.

Pipelines should under no circumstances be bonded to power line towers, tower counterpoises, substation earth grids, power cable screens or any other earthed component of MV, HV or EHV a.c. power networks, as any surges in the power network would then be transferred directly to the pipeline.

Bonding to the earthing of any other infrastructure that is not well defined should generally be avoided.

3.7.1.9 Insulating flanges

Insulating flanges can be used to sectionalise the pipeline and thereby reduce the accumulated voltage in a parallelism. They can also be used to prevent transferred potentials, for example on pipeline spurs or tees.

As each section created requires a separate CP station, this mitigation method can be uneconomical.

Insulating flanges are typically rated less than 15 kV, and a surge diverter with a 1.2 kV breakdown voltage is usually supplied with the unit to prevent damage to the flange in case of lightning –induced voltage surges. If used for AC mitigation purposes, breakdown may not occur during earth faults, as this would defeat the purpose of the insulating flange.

Insulating flanges are not effective with pipelines transporting water or other conductive media, unless an inner lining with the appropriate dielectric properties is used.

When installed in areas where stray d.c. currents are expected, insulating flanges must be housed in an underground chamber to prevent potentially large d.c. currents bypassing the flange through the surrounding soil, which can cause severe localised corrosion.

3.7.1.10 Pipeline coatings and coating integrity surveys

The most beneficial pipeline coating type from an a.c. mitigation viewpoint depends on the type of coupling that is most pronounced or problematic. Inductive coupling levels and transferred potentials can be significantly reduced by low resistivity coatings such as bitumen or modified bitumen, especially on long pipelines.

Conductive coupling and d.c. leakage in particular is, on the other hand, greatly reduced or even effectively eliminated by the use of high resistivity PE, rigid PU or epoxy coatings. These coatings are also more tolerant of high voltage gradients during earth faults and would hence be preferred if the pipeline is very close to several power line towers.

Increasing the coating thickness near power line towers can also be a very effective method of mitigation, as this reduces the risk of coating damage. This can be done during the coating process at the supplier, or by a procedure referred to as armour wrapping, where membrane layers and bitumen are applied over the existing coating on site.

The risk of having any significant coating defects near tower footings may be further mitigated by a post-installation coating integrity (e.g. DCVG) survey to locate and repair any coating defects.

3.7.1.11 Location selection of anode ground beds

Anode ground beds should preferably be located at least 1 km away from any earthed power installation, and with the pipeline positioned in between. In practice the location is confined to areas of low earth resistivity with an available LV or MV supply point and maintaining this separation with power lines is not always possible. In such cases it may be necessary to insulate the earth wires of the nearest towers.

Locating the anode bed close to substations is never advisable as in this can cause a much larger current to enter the power system through the earthing grid, given the grid’s lower impedance and greater footprint. All the towers of the power lines connected to the substation then become the drain points and therefore potential corrosion sites.

3.7.1.12 Considerations for pipelines near utility-scale PV systems

As indicated in par. 3.4.2.5, the overall impact of d.c. leakage currents from large PV plants on buried metallic pipelines still being assessed. PV plants also use different earthing systems (e.g. negative earthed, floating isolated or floating non-isolated), each with a different leakage current pattern.

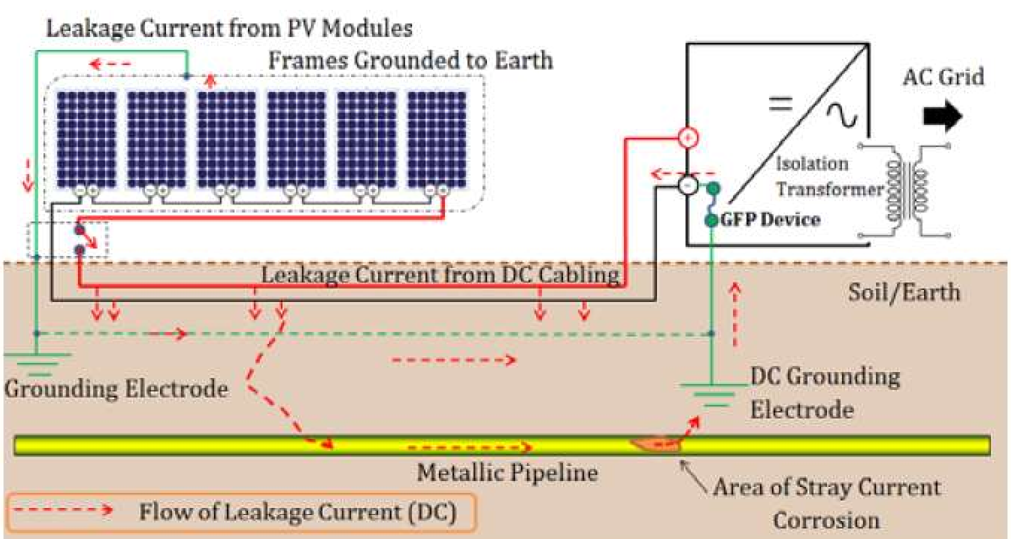


Figure 23: Stray current path in the case of a negative earthed PV system (from [36])

One possible scenario with a negative earthed system is depicted in fig 23. With this system, leakage currents from the frames and cabling entering the pipeline will discharge near the inverter's d.c. earthing electrode, with the resultant corrosion risk in this area.

With no definitive standards or guidelines available, the only recommendation is to install sufficient tests posts with d.c. coupons or probes on pipelines traversing a PV plant, to enable monitoring of the pipe-to-soil potential and the corrosion rate.

Where these measurements reveal anodic conditions, directional drainage bonds (similar to those used at d.c. railway crossings, see 3.7.1.8) may be considered. In the example of fig 20, such a drainage bond would be connected between the pipeline and the d.c. earthing electrode of the inverter substation.

3.7.1.13 Temporary bonds during pipe cutting and replacement

Before cutting or replacing a damaged section of a pipeline subject to inductive coupling from power lines, temporary bonds must be applied across the joints or cuts of the section to be replaced, to retain the pipeline's electrical continuity. This is required to prevent hazardous voltages from developing across the openings. The bonding cable cross-section should be at least 16 mm^2 Cu or 25 mm^2 Al.

These bonds may not be removed until the new pipe section has been fully bolted or welded in place.

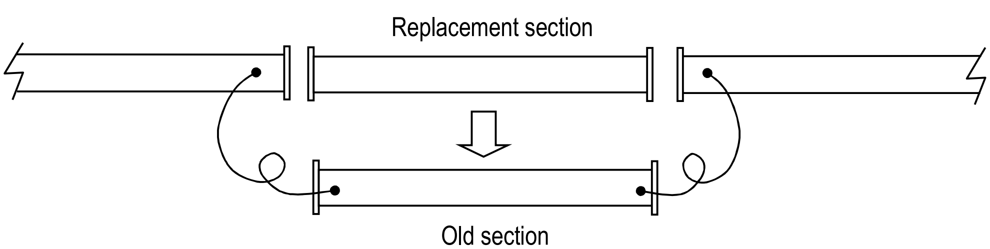


Figure 24: Temporary bonds during pipe replacement

3.7.2 Mitigation measures applicable to power lines

3.7.2.1 Routing of the power line

Re-routing the power line away from the pipeline may be an option for new power lines. See 3.7.1.1.

3.7.2.2 Use of ACSR as power line earth wires

Using ACSR instead of steel earth wires on power lines improves the screening factor for inductive coupling during earth faults. By suitable selection of conductor type, a 40 % to 60 % reduction of the induced voltage is usually achievable.

Using ACSR earth wires also results in an important reduction of a faulted tower's EPR, and therefore the level of conducted coupling from power line towers.

3.7.2.3 Use of power cables with improved screening factor

Inductive coupling from MV/HV power cables can be reduced by selecting a cable with an improved screening factor, for example cables with thick aluminium sheaths.

3.7.2.4 Employ a power system with isolated or high impedance neutral

Power lines with isolated or high impedance transformer neutrals have significantly lower earth fault current levels than power lines with earthed transformer neutrals. This method concerns voltages induced during earth faults and may be an option for certain MV and HV power systems.

3.7.2.5 Use of phase arrangements to reduce steady-state coupling

When the power line carries two or more circuits, an appropriate choice of phase arrangement can result in a significant reduction of the steady-state voltages induced on a parallel pipeline, if this option is available. For example, for a vertical 2 circuit line, a centre-point symmetric phase arrangement will result in the lowest voltages (see fig 10).

Changing phase arrangements is not effective for reducing induced voltages during earth faults.

3.7.2.6 Earth wire insulation to prevent tower footing corrosion

Isolating the towers in the EPR zone of a d.c. energised pipeline or anode ground bed with insulators at the earth wire attachment points will prevent the circulation of d.c. currents on the earth wires and the associated corrosion.

3.7.2.7 Sacrificial anodes to prevent tower footing corrosion

Magnesium or zinc anodes connected to the tower footing or guy anchors when the positive d.c. potential shift exceeds the required 200 mV limit, will prevent damage to the footing. Anodes for this purpose must be designed according to the actual soil characteristics and the measured d.c. potential shift with the maximum CP current applied.

3.8 Safe working procedures in power line servitudes

3.8.1 Appointment of Electrical Safety Officer (ESO)

3.8.1.1 Prior to any work commencing an Electrical Safety Officer (ESO) shall be appointed by the PO or the PO’s agent. This person shall:

a) either be the designated safety officer for the project, or else report directly to him or her,

b) have completed Eskom’s ORHVS responsible person training course,

c) be authorised by a ORHVS authorised person (GMR2.1) to work without constant supervision in a power line servitude,

d) have experience in the supervision and management of temporary mitigation measures during pipeline construction,

e) be furnished with the authority and equipment required to implement and maintain safe working conditions,

f) present daily safety briefings to all workers and personnel that will enter the affected area, covering the applicable ORHVS and safe working procedures of par. 3.8.2 – 3.8.7,

g) keep a record of any non-compliance and advise the construction manager and the project safety officer,

h) comply with the regulations in 240-86640998, Supervision of people in electrically hazardous locations [37].

3.8.2 General Safe Working procedures

1) No person, equipment or machinery shall enter the HV/EHV servitude without the approval of the ESO. All affected areas shall be suitably demarcated, and access restricted to those personnel who have been briefed on the hazards and requirements when working underneath or adjacent to HV/EHV power lines.

2) All personnel shall be made aware of and be able to recognize the potential shock hazards and be trained in the approved safety procedures.

3) Pipeline construction personnel shall avoid contact with HV/EHV structures and supports. No mechanical equipment shall come closer than 5 m from any power line tower.

4) No excavations are permitted within the following distances of above-ground power line structures (as measured from the nearest tower leg, pole mast, guy anchor or other attachment) without written permission from Eskom:

   i. Transmission lines: 20 m

   ii. Distribution lines: 6 m

5) Direct connections to the power line tower structures or buried counterpoise earthing system are not permitted under any circumstances. The earthing systems of the power line and the pipeline must be kept separate.

6) Temporary construction sheds, trailers, living quarters, pipe sections, storage areas or vehicle fuelling facilities are not permitted in the HV/EHV servitude.

7) No mechanical equipment, including mechanical excavators or high lifting machinery, shall be used in the vicinity of Eskom's apparatus and/or services, without prior written permission having been granted by Eskom. If such permission is granted the applicant must give at least seven working days prior notice of the commencement of work. This allows time for arrangements to be made for supervision and/or precautionary instructions to be issued. The internal assessor must provide the applicant with the details of an Eskom person to be contacted in this regard.

8) All rubber tyre construction vehicles used in the HV/EHV servitude shall be equipped with a steel chain secured to the chassis at one end and freely dragging on the earth at the other, to discharge any electrostatic build-up.

9) The minimum vertical clearance between construction equipment and overhead conductors shall be in accordance with Table 16. The actual height of the conductors at their lowest point shall be measured by means of optical measuring equipment to ensure that this minimum clearance is achieved.

Table 16: Minimum vertical clearance underneath power line conductors

Nominal r.m.s. voltage (kV)	66	88	132	220	275	400	533 d.c.	765
Minimum vertical clearance (m)	3.2	3.4	3.8	4.5	4.9	5.6	6.1	8.5

(from Regulation 15 of the Electrical Machinery Regulations of the OHS Act (Act 85 of 1993))

10) Vehicles such as mobile cranes with extendable members that can potentially exceed this minimum vertical clearance height shall be identified and the operators issued with specific instructions regarding the maximum permissible extension, prior to doing any work in the HV/EHV servitude.

11) If for any unforeseen reason, the life-threatening situation occurs where a construction vehicle comes into contact with a live HV/EHV conductor or a flash-over occurs, the operator(s) shall remain inside the vehicle and attempt to get it out of the contact situation using ONLY the vehicle's own power. On NO account shall the operator(s) leave the vehicle and on NO account shall any person approach the vehicle, until the contact situation has been reversed, or until the ESO has received confirmation from the electricity utility that the power line has been de-energized. Arcing may temporarily stop due to the action of the protection, however this shall NOT be taken as an indication that the line is safe, since the line may automatically attempt to re-energize. Effective assistance in this situation entails ensuring that all persons present maintain a safe distance from the vehicle (>10 m) and alarming the electricity utility's operational centre.

12) Any foreign metal structures exposed during trenching inside or alongside HV/EHV servitudes shall be treated as a live electrical conductor, until measurement proves otherwise. The pipeline shall not be bonded any foreign structures without an assessment by a qualified engineer and written permission from the owner.

13) The use, storage, disposal, treatment or generation of any hazardous substances shall not be permitted in the power line servitude.

3.8.3 Daily measurements

1) Qualified personnel shall measure and record the pipeline voltage to earth to verify that conditions are safe to work (a.c. touch potential < 15 V r.m.s.), on all sections and on each day prior to the commencement of any construction or other activity involving contact with the pipeline.

2) For pipeline voltage measurements, a voltmeter of suitable range and impedance shall be used. As reference, a low resistance earth connection shall be used to avoid erroneous readings on a high impedance instrument as a result of inductive or capacitive pickup on test leads. A suitable reference is a metal rod driven into the soil, at a distance not closer than 1 m from the pipeline.

3) The metal rod shall not be driven into the soil over or close to buried metallic structures, gradient control mats or temporary earthing as this may result in misleading readings. The distance between the metal rod and any buried metallic structure or temporary earthing shall be at least 5 m or 5x the structure's maximum dimension (whichever is greater).

4) Test leads shall be attached to the instrument first and then to the pipeline. After measurement, the leads shall be removed from the pipeline first and from the instrument last.

5) Each time a voltage measurement is made, the following data shall be recorded:

   i. location,
   ii. time,
   iii. date, and
   iv. pipe-to-earth voltage.

3.8.4 Temporary earthing

1) Pipelines exhibiting voltages greater than 15 V r.m.s. shall be earthed with temporary driven earth rods. Pipelines parallel to a.c. power systems shall be earthed opposite the midpoint of each span, maximising the distance to the nearest HV/EHV structure.

2) The temporary connections to the pipeline shall be made with earthing clamps that apply firm pressure at the contact point with a mechanically sound connection, and with the coating at the contact point removed down to the bare metal.

3) The connection between the earthing clamp and the earth rod shall be made with 25 mm² stranded copper cable, green PVC insulated.

4) To prevent the risk of personal injury or arc burns, the connection and disconnection of temporary earths shall be carried out in the following order:

   a) connection:

      i. the earthing clamp is connected to the pipeline,
      ii. the earthing cable is connected to the earth rod,
      iii. the earthing cable is connected to the earthing clamp.

   b) disconnection:

      i. the earthing cable is disconnected from the earthing clamp,
      ii. the earthing cable is disconnected from the earth rod,

iii. the earthing clamp is removed from the pipeline.

5) Temporary earths shall be left in place until immediately prior to backfilling. Sufficient temporary earths shall be maintained on each section until adequate permanent grounding connections have been made.

6) When the pipeline voltage remains above 15 V r.m.s. despite the temporary earth rods, temporary earth mats that extend a minimum of 1 m outside the work area shall be used. The connection between the pipeline earthing clamp and the temporary earth mat shall be made with 16 mm2 or larger stranded copper cable. There shall be no contact between persons over the earth mat and those not over the mat, including the handing over of tools or materials.

3.8.5 Bonding of insulating flanges, joints and couplings

1) Work on insulating flanges, joints, or couplings shall only proceed after the AC status has been verified. A temporary bond across the flange or the use of a properly sized temporary earth mat shall be used to protect personnel while they work on the pipe.

2) When cutting a pipeline, adequate bonding across the point to be cut shall be used, irrespective of the AC voltage measured between the pipeline and earth. When this voltage exceeds 15 V r.m.s, additional earthing shall be installed BEFORE cutting commences.

3.8.6 Precautions during coating and lowering-in operations

1) Where coating is to be applied at field joints, precautions shall be taken to ensure that equipment contacting the bare pipe is adequately bonded and earthed.

2) For the lowering-in operation, the coated pipeline shall be handled with nonconductive slings. Because the coated pipeline may not be effectively earthed during part of this operation, contact with the bare portion of the pipeline shall be avoided when the support slings are removed from the end of the pipeline.

3.8.7 Work stoppage

1) The ESO shall have liaison with the electrical utility to determine planned switching, outages, and load changes that may affect pipeline voltage. Work involving contact with the pipeline shall be stopped during scheduled switching of the electric power system.

2) The ESO shall stay informed daily of the predicted weather conditions at the construction site and order a discontinuation of work when thunderstorms are expected.

3) WORK SHALL BE STOPPED WHEN ANY LIGHTNING ACTIVITY IS OBSERVED.

3.9 Inspection and testing and of pipeline a.c. mitigation components prior to commissioning

a) When the a.c. mitigation measures agreed upon by the Eskom and the Pipeline Operator have been installed, an Eskom representative shall be permitted to inspect all the components of this installation and to perform necessary measurements according to the inspection sheet provided in Annex D.

b) Final approval of the a.c. mitigation installation is subject to the outcome of this inspection.

3.10 Long term maintenance requirements of pipeline and power line a.c. mitigation components

a) The a.c. mitigation measures shall be maintained by regular inspection and measurement of the effectiveness of the measures. The interval between inspections shall not exceed 6 months.

b) Maintenance personnel shall be provided with special training to acquaint them with the a.c. mitigation components, measurements and safety requirements.

c) Clear and detailed maintenance records shall be kept available for inspection by an Eskom representative for the full operational lifetime of the pipeline.

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
V Singh	Power Plant Technologies Manager
AA Burger	Chief Engineer – Eskom Lines Engineering Services
B Haridass	Chief Engineer – Eskom Lines Engineering Services
L Makwentshu	Tx/NTCSA Land Development Manager
B van Geems	Chief Advisor Geoscience – Asset Creation CoE, Operations Enablement
X Songcaka	Land Development Manager: Western Cape, Eastern Cape
D Harding	Land Development Manager: Northern Cape
N Galela	Land Development Manager: North West
G Jordan	Land Development Manager: Free State
N Mdunyelwa	Land Development Manager: KwaZulu-Natal
V Phalanndwa	Land Development Manager: Gauteng
B Maudu	Land Development Manager: Limpopo, Mpumalanga

5. Revisions

Date	Rev.	Compiler	Remarks
May 2015	Rev 1	B Druif/A Burger	First issue.
Mar 2024	Rev 2	B Druif	Second issue, with amendments covering: - updated criteria for a.c.-induced pipeline corrosion based on the latest research, - introduction of a risk-based analysis to establish the tolerable risk at co-locations, - effect of utility-scale PV installations on nearby pipelines, - updated power line steady state load limits and conductor types in use, - revised dielectric strength of pipe coatings, - revised equipotential bonding methods inside and outside valve chambers, - revised protective device specifications, - protective measures for areas with a high risk of vandalism.

6. Development team

This guideline was prepared for Line Engineering Services by a Working Group that comprised the following members:

B Haridass	Eskom Line Engineering Services
A Burger	Eskom Line Engineering Services
L Motsisi	Eskom Land & Rights
B Druif	EM Consulting
P H Pretorius	Terratech

7. Acknowledgements

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Members of the SABS's Power line and Pipeline Working Group that were consulted during the drafting of this guideline were:

E Livesly	Johannesburg Water
T Madonsela	Rand Water
A Nxumalo	Rand Water
T Mofokeng	Rand Water
B Lourence	Department of Water Affairs
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R Manenzhe	Sasol
Z Mkhonto	Sasol
M Rudzani	Sasol
B Burger	Transnet
C Downs	Transnet
T Moekoa	Transnet
L Molemi	Transnet
T du Plessis	Eskom
C Mampane	Eskom Line Engineering Services
S Manqele	Eskom Transmission
F Mokhonoana	Eskom Line Engineering Services
L Motsisi	Eskom Land & Rights
S Mushabe	Eskom Line Engineering Services
S Ramadhin	Eskom Line Engineering Services
T Sibi	Eskom Line Engineering Services
K R Hubbard	Independent consultant
V Sewchand	Eskom Technology Standardization
F Thuynsma	Eskom Industry Association Resource Centre

T Mundie	Trans-Africa Projects
N Webb	Isinyithi Cathodic Protection
V Sealy-Fisher	Isinyithi Cathodic Protection
D Hovy	Isinyithi Electrical Protection
L Middelberg	LR Middelberg Consulting Engineers
N Otto	PPT Engineering Services
C Ringas	PPT Engineering Services
N Ringas	PPT Engineering Services
A Schwab	PPT Engineering Services
G Haynes	Corrosion &Technology Consultants
T Mushiri	Mabro
N Shago	Mabro
C Botha	Reignite
D Carter	LMC Corrosion
R Pillay	Paradigm Projects
M Lebenya	Paradigm Projects
S Moodley	Integrityafrica
G Turner	Pipe and Tank Africa Consultants
A Copley	IMESA
E Peralta	Disa Anodes
B Nkambule	Ekuhurleni Metro
D Raath	Cathtect Engineering
J Mtombeni	SABS

Annex A – Checklists of particulars required

A.1 - Pipeline Details

1.1	Pipeline name:	
1.2	Pipeline construction start date:	
	Pipeline construction completion date:	
1.3	Pipeline pumped product(s):	
1.4	Pipeline outer diameter (mm):	
	Wall thickness (mm):	
	Wall material:	
	Section lengths if sectionalised (m):	
1.5	Pipeline height / burial depth @ centreline (+/- m):	
	Pipeline or appurtenances exposed to the public? Y/N	
1.6	Coating type and material:	
	Thickness (mm):	
	Final insulation strength (kV):	
	Resistivity (Ω.m) *OR* Specific Resistance ($\Omega.m^2$):	
	Relative permittivity:	
1.7	Pipeline route map or .kmz attached (see Note 1):	
1.8	All available soil resistivity data attached:	
1.9	Details of cathodic protection attached (see Note 2):	
1.10	Details of lightning protection attached (e.g. spark gaps, surge protectors across isolating joints):	
1.11	Drawings of valve chambers, pump stations, reservoirs, test post, etc. attached, showing structural steel and other earthing, and final height/level:	
1.12	Details of any existing adjacent pipelines, cables, railways and other earthed structures attached:	
1.13	Details of all construction vehicles to be used in power line servitude (incl. maximum extended height of booms, vehicles causing excessive vibration etc.) attached:	
1.14	Details of activities which will occur (e.g. excavation, blasting, lifting by crane, maintenance inspections by helicopter etc.) provided (see Note 3):	

***NOTE 1**: Clearly indicate the location of all bend points, pump stations, reservoirs, tanks, valve chambers, off takes, test posts and isolating joints*

***NOTE 2:** For ICCP systems, indicate the location and DC current of all anode ground beds and the maximum CP current density expected on the pipeline*

***NOTE 3:** Written approval is required for blasting within 500 m of Eskom's structures, see B.7 and C.7 of* 240-61227332

Approved by: ______________________ **Date:** ____________________

Pipeline Applicant / Technical Representative: ______________________________.

A.2 – Identification of existing and future power lines / cables affected

		Line Name	**Voltage Level**	**Tx, Dx or other?**
2.1	Existing and planned power lines or cables crossing or running parallel to the pipeline, within 6 km separation distance for overhead lines or 1 km for cables (ignore overhead lines and cables below 11 kV, and ignore 11 kV – 33 kV overhead lines for parallelisms < 3 km *or* separations > 500 m)			

		Substation Name	**Voltage Level**	**Tx, Dx or other?**
2.2	Existing and planned substations within 3 km separation distance from the pipeline (ignore substations with overhead lines below 44 kV only or with cables below 11 kV only)			

2.3	Maps showing route of relevant lines/cables and location of substations attached (alternatively the .kmz, .gdb or .dxf route files):	

<u>Approved by</u>: ___________________________ **<u>Date:</u>** __________________________

GIS Specialist / Land & Rights representative: ____.

A.3 - Overhead power line details (complete for each overhead line listed in A.2.1)

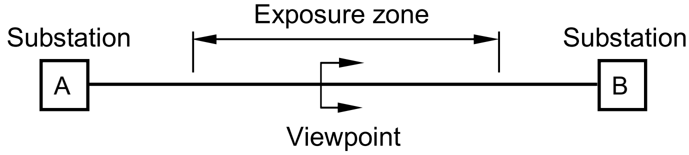

Figure A.1 - Plan view of power line

3.1	System Voltage (V r.m.s., phase-phase):	
3.2	Station A: Station B:	
3.3	Number of circuits:	
3.4	Power line total length (km): Start of exposure at (km): End of exposure at (km):	
3.5	Transposition(s) at (km) (or None):	
3.6	Dominant tower type no. in exposure zone: Tower sketch attached showing phase and earth conductor attachment height and separation (Y/N): Avg. span length (m): Avg. conductor sag at midspan (m): Avg. tower footing resistance (ohm):	*(see Note)*
3.7	Phase conductor type and trade name: Number of sub-conductors: Spacing between sub-conductors (m): Earth wire conductor type and trade name: Earth wires insulated from towers at tower number(s) (or None):	
3.8	Peak load current (A r.m.s.): Emergency load current (A r.m.s.): Maximum load unbalance between phases (%)	

NOTE: *Indicate conductor phases (R/W/B) on sketch (at start of exposure, looking towards station B, and if applicable, after each transposition in the exposure)*

Approved by:____________________________ **Date:** ____________________________

Power Line Design / Engineering representative: ____________________________________.

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A.4 - Fault current levels

		Line Name	Sub Start fault level (kA)	Sub End fault level (kA)
4.1	Maximum 1 phase-earth fault level at each substation of each power line listed in 2.1 over next 20 years, on the busbar connected to the line			

		Substation Name	Maximum fault current (kA)	On busbar of voltage (kV)
4.4	Maximum 1 phase – earth fault current at each substation listed in 2.2 over next 20 years			

4.5	Planning case file (rev number and date)	

Approved by:______________________________ **Date:** ____________________________

Power Line Design / Engineering representative: _____________________________________.

Annex B – Specification of Mitigation Components

B.1 Gradient control wire

Gradient control wires shall be zinc ribbon. The composition of the zinc shall be as per ASTM B418 – 95 – Type II, with a steel wire inner core. The ribbon shall be of the following specification:

a) Cross section (D1 x D2): 12.7 mm x 14.3 mm

b) Radii (R1 x R2): 2 mm x 5 mm

c) Zinc weight: 0.89 kg/m

d) Core wire diameter: 3.3 mm

e) Potential: -1.1 V vs. $Cu/CuSO_4$ electrode

f) Capacity: 780 Ah/kg

The gradient control wire, where required, shall be installed in the corners of the trench. Fig B.1 shows a section with two gradient control wires. A minimum lateral separation distance to the pipeline of 200 mm shall be maintained. In the case of a single gradient control wire, the wire shall be installed in either corner of the trench.

The gradient wire shall be covered with either native soil (sifted if necessary) or with a gypsum / bentonite mixture, prior to the bedding material.

The gradient control wire shall comprise discrete sections of up to (but not exceeding) 400 m in length. The ends of successive sections shall not be in direct contact.

The connection to the pipeline shall be made near the centre of each section, using a d.c. decoupling device for ICCP equipped pipelines, or a direct bonding link when no ICCP is used and the gradient control wires are used as sacrificial anodes.

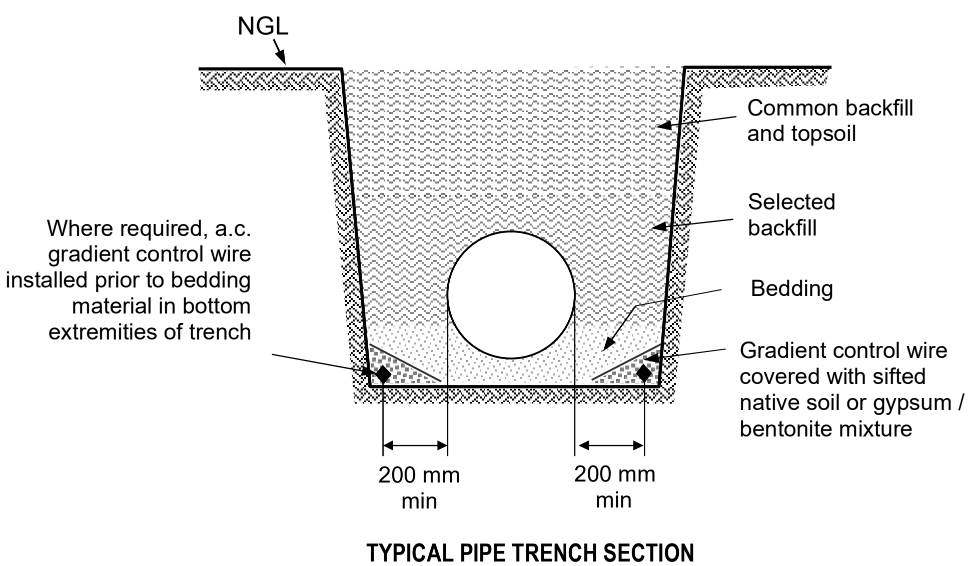


Figure B.1 – Installation of gradient control wire in trench

B.2 Decoupling devices for gradient control wire

For pipelines equipped with ICCP systems, the zinc ribbon shall not be connected to the pipeline directly but only through a solid state d.c. decoupling device, housed in a valve chamber or a dedicated a.c. mitigation station. The device shall be certified by a suitably accredited test laboratory to meet the specifications given in Table B.1:

Table B.1 - Performance specification for d.c. decoupling device for gradient control wire

No	Specification / Test	Level / Requirement	Comment
1	Class I impulse current1)	10 kA, 10/350 μsec2)	to SANS 61643-1 requirement
2	Class II impulse current	20 kA, 8/20 μsec2)	to SANS 61643-1 requirement
3	Front of wave spark-over voltage	≤ 500 V, 1.2/50 μsec	to SANS 61643-1 requirement
4	Rated a.c. short circuit	3.7 kA r.m.s., 0.5 sec, 50 Hz	to SANS 61643-1 requirement
5	Rated a.c. load current	45 A r.m.s., 50 Hz, max temp incr. 40˚ C	at maximum d.c. blocking voltage, to SANS 61643-1 requirement
6	a.c. impedance	≤ 0.04 Ohm	at rated load current
7	d.c. blocking voltage	-12 V/+1V (+/- 10%)	If not influenced by spurious d.c. (railway, anode ground bed), reduce to -3V/+1V
8	d.c. leakage (blocked)	≤ 1 mA	at a.c. load thermal limit
9	d.c. current withstand	60 A for 15 mins	without overheating, test in both directions
11	Housing dielectric withstand voltage	5.8 kV	to SANS 61643-1 requirement
12	Environmental, enclosure	IP55	adjust upwards for more extreme environments
13	Ambient temperature range	-15˚ C to 60˚ C	
14	Air clearance and creepage distances	10 mm, 15 mm min resp.	to SANS 61643-1 requirement
15	Protection against direct contact	no direct contact	using IEC60529 test finger
16	Ex-rating	see Note 5	

Notes:

1) A Class I device is required only for installations exceeding tolerable risk factors i.t.o. SANS 62305-2 (e.g. when the a.c. mitigation station is exposed to direct lightning strikes) and the device is used in combination with an external LPS (Lightning Protection System). LPS design is outside the scope of this document, see SANS 10313 and SANS 62305-3 for further information.

2) Devices subject to degradation must sustain this impulse level at least 5 times prior to failure. Sufficient time to cool is permitted between testing.

3) If housed in a location classified as hazardous in SANS 10108 and ARP 0108, e.g. as encountered with gas or fuel pipelines, the decoupler shall be explosion proof (Ex-rated). The nature of the Ex-rating required and the applicable test standard shall be determined by a specialist following a classification study in accordance with SANS 10108.

Additional requirements for the d.c. decoupling device are:

a) The decoupling device shall comprise a suitably rated diode stack capable of blocking direct current in both directions at the specified voltages.

b) The device shall exhibit a progressive, smooth transition from blocking to conduction and vice versa without commutating.

c) A bypass capacitor (network) shall be connected in parallel with the diode stack to conduct 50Hz a.c. up to the blocking voltage of the diode stack.

d) The capacitor and diode network shall be protected by a suitably rated SPD for high voltage and lightning-induced transients. The SPD shall be decoupled from the capacitor and diode network with the appropriate inductance, in accordance with SANS 61312-3. This inductance shall remain effective (i.e. not saturated) during simultaneous transient and maximum d.c. current conditions.

e) The decoupling device shall preferably be of open frame construction to permit maintenance and replacement of component parts. The frame shall be sized to fit on a standard 800 mm x 600 mm chassis plate.

f) The decoupling device shall be provided with two M10 terminals at each installation point for the connection of 25 mm² single core cables.

B.3 Valve chamber gradient control

The preferred method of implementing gradient control mats is with steel weld mesh encased in concrete. Zinc spirals have relatively poor high frequency performance and are more prone to vandalism. An example of a steel weld mesh mat around a valve chamber is shown in Fig B.2. The following is required:

<u>For external gradient control:</u>

a) A 200 mm x 200 mm weld mesh of 6 mm diameter steel wire, not galvanized, extending 1.2 m beyond the external wall of the chamber.

b) All overlaps shall be 100 mm minimum, joined at two (2) places with crimped ferrules.

c) For 2 m circular chambers the weld mesh shall be two overlapping panels with a circular cut-out to achieve a 4.4 m x 4.4 m square surround.

d) The weld mesh is centrally located in minimally 85 mm thick, 15/19 MPa concrete encasement.

e) The minimum depth of the weld mesh is 300 mm below normal ground level.

f) The panels are connected to the pipeline with at least two (2) cables through a VLD, cables kept as short as possible (≤ 1.5 m) (see B.4 and B.5).

<u>For internal gradient control:</u>

g) Continuity of the floor reinforcing is ensured by securely bonding (i.e. by means of welding or clamping, not just by steel tie-wires) a continuous bar to at least 4 evenly spaced crossing bars, prior to the concrete pour.

h) Continuity of the wall reinforcing is ensured by a continuity ring installed just below roof height and securely bonded (by welding or clamping) to at least 4 vertical bars (e.g. in the corners) prior to the concrete pour, and to a connector plate or earthing boss protruding through the wall.

i) To ensure floor-to-wall continuity, at least one of these bonded vertical bars must be securely bonded (by welding or clamping) to the one of the floor bars as discussed in (g). Ring continuity is ensured by securely bonding any joints or overlaps in the same manner.

j) If welding or clamping of the reinforcing bars is not permitted, a weld mesh layer (not galvanized, cut to the floor size) is installed above the structural re-bar (see fig B.3).

k) The connector plate or earthing boss is connected to the pipeline with two (2) cables through a VLD, cables kept as short as possible (≤ 1.5 m) (see B.4 and B.5).

l) If there is any likelihood of a galvanic cell forming between the steel reinforcing bar and the external weld mesh (i.e. dissimilar metals or dissimilar concrete encasement), two separate voltage limiting devices shall be used, as shown in Fig B.2.

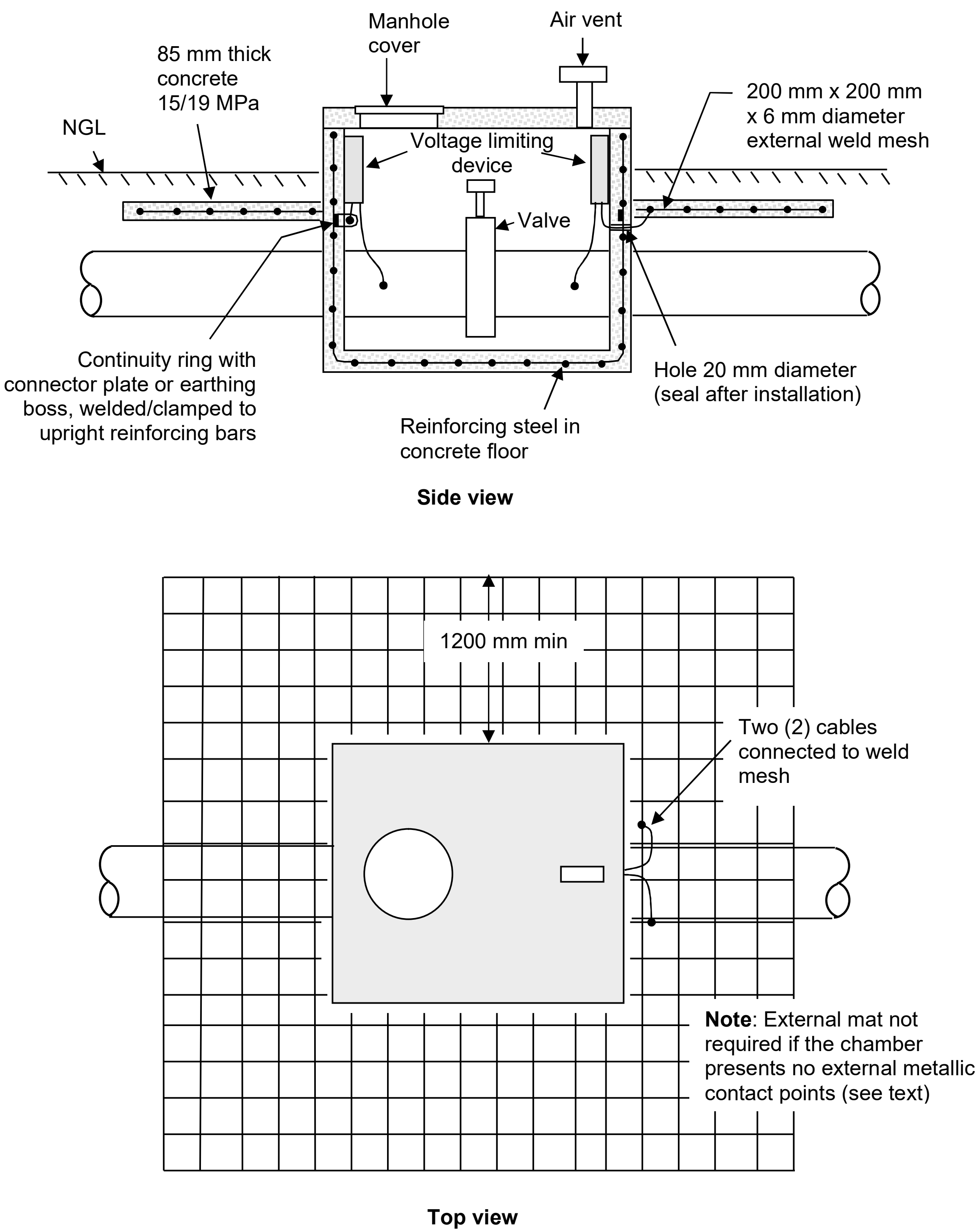


Figure B.2 – Valve chamber with external weld mesh gradient control mat

m) If there is a distinct risk of vandalism, temporary jumpers are used in the chamber in lieu of permanent cables and VLDs (see B.6).

n) For air valves with the chamber situated above the pipeline, the mat may be installed at the same depth as the chamber floor.

o) For air valve chambers using pre-cast concrete rings as walls, the steel reinforcing is generally inaccessible and only the reinforcing in the concrete floor is connected to the pipeline.

Note that the external gradient control is not required if there are no metallic chamber components within reach of a person standing on the ground next to the chamber, provided the step voltages are within the limits of table 1.

When external gradient control is required but the step and touch voltages around the chamber do not exceed the values indicated for asphalt cover in table 1, the external gradient control mat may be replaced by external asphalt cover, as shown in Fig B.3.

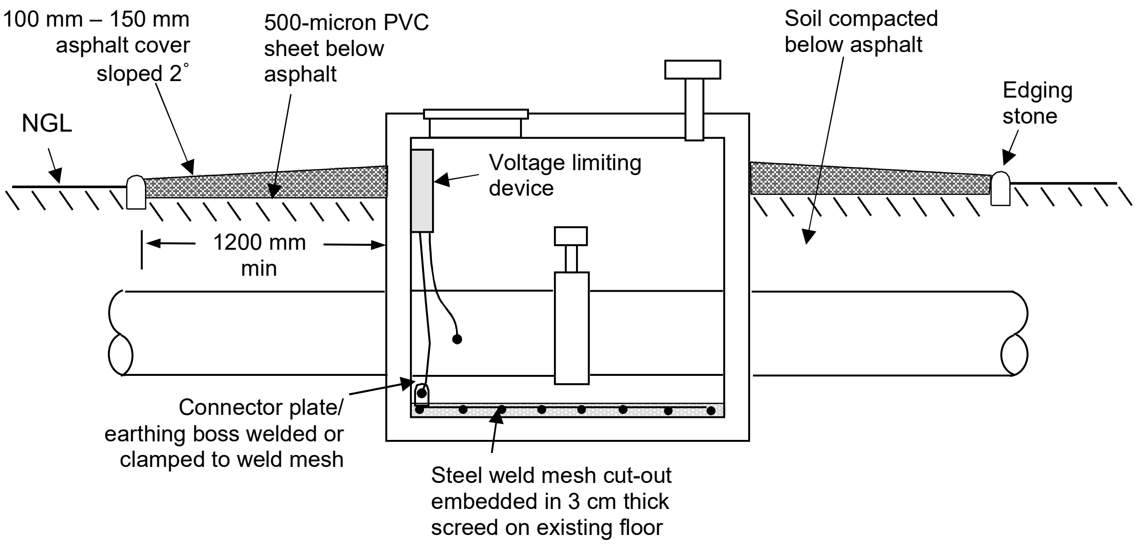


Figure B.3 – Valve chamber with external asphalt cover and internal gradient control mat

Fig B.3 also shows an alternative internal arrangement, suitable when access the steel reinforcing it is not possible. This method would be applied to existing valve chambers, to new valve chambers without reinforcing steel, or when for any reason, welding or clamping of the reinforcing bars is not permitted.

The installation requirements in this case are:

m) compact soil and install asphalt cover of 100 mm or thicker, extending to 1.2 m around the chamber, suitably sloped for surface water dispersion away from chamber (2˚ min),

n) use 500 µm thick PVC sheet below asphalt to prevent weed growth through cracks,

o) install weld mesh cut-out on chamber floor, comprising 200 mm x 200 m x 6 mm diameter steel weld mesh, not galvanized, and with a suitable connector plate or earthing boss, welded or clamped to the weld mesh,

p) where required, weld mesh sections overlap by at least 100 mm, connect with at least two (2) crimped ferrule connections,

q) weld mesh embedded in a thin (3 cm) layer of screed, sloped as required for water dispersion,

r) use VLD to connect the weld mesh to the pipeline using at least two (2) connections (see B.4, B.5), or use a temporary connection instead in areas affected by vandalism (see B.6),

s) all cables kept as short as possible (≤ 1.5 m).

B.4 Voltage limiting devices for gradient control mats

For pipelines equipped with ICCP systems, the gradient control mats or valve chamber reinforcing steel shall not be connected to the pipeline directly but only through a voltage limiting device.

An SPD (e.g. a MOV or GDT) shall be used for this purpose. The device shall be certified by a suitably accredited test laboratory to meet the specifications given in Table B.2:

Table B.2 - Performance specification for VLDs used with gradient control mats

No	Specification / Test	Level / Requirement	Comment
1	Class I impulse current1)	10 kA, 10/350 µsec2)	to SANS 61643-1 requirement
2	Class II impulse current	20 kA, 8/20 µsec2)	to SANS 61643-1 requirement
3	Front of wave spark over voltage	≤ 500 V, 1.2/50 µsec	to SANS 61643-1 requirement
4	Response time	≤ 100 nsec	
5	a.c. short circuit withstand	3.7 kA r.m.s., 0.5 sec, 50 Hz	lower current rating permitted if the calculated maximum current level during a power line fault is lower to SANS 61643-1 requirement
6	Housing dielectric withstand voltage	5.8 kV	to SANS 61643-1 requirement
7	a.c. clamping voltage	75 V r.m.s. (+/- 10%)	higher voltages (not exceeding the applicable level of Table 1) permitted for fault durations < 0.5 sec
8	d.c. breakdown voltage	100 V (+/- 10%)	higher voltages permitted up to 1.4 x the a.c. clamping voltage
9	d.c. leakage (blocked)	≤ 1 mA	
10	Environmental, enclosure	IP55	adjust upwards for more extreme environments
11	Ambient temperature	-15˚ C to 60˚ C	
12	Air clearance and creepage distances	10 mm, 40 mm resp.	to SANS 61643-1 requirement
13	Protection against direct contact	no direct contact	using IEC 60529 test finger
14	Device failure indicator	Mechanical flag3)	for MOV devices only – for GDT devices see Note 4.
15	Ex-rating	see Note 5	

Notes:

1) A Class I device is required only for installations exceeding tolerable risk factors i.t.o. SANS 62305-2 (e.g. when the valve chamber is exposed to direct lightning strikes) and the device is used in combination with an external LPS (Lightning Protection System). LPS design is outside the scope of this document, see SANS 10313 and SANS 62305-3 for further information.

2) Devices subject to degradation must sustain this impulse level at least 5 times prior to failure. Sufficient time to cool is permitted between testing.

3) Mechanical flag must operate independently, i.e. without a line supply.

4) VLDs using a GDT must allow view of the GDT for inspection purposes. Damaged or blackened glass or ceramic would indicate device failure. Potting of GDTs is not permitted.

5) If housed in a location classified as hazardous in SANS 10108 and ARP 0108, e.g. with gas or fuel pipelines, the VLD shall be explosion proof (Ex-rated). The nature of the Ex-rating required and the applicable test standard shall be determined by a specialist following a classification study in accordance with SANS 10108.

B.5 Cabling

For connecting of d.c. decoupling devices to the pipeline, insulated 25 mm^2 copper (Cu/PVC) or 35 mm^2 aluminium (Al/PVC) earth cables shall be used.

For connection of VLDs to the pipeline, insulated 16 mm^2 copper or 25 mm^2 aluminium earth cables shall be used.

Copper or aluminium earth cables shall have a green and yellow colour combination, shall be doubled for redundancy and shall be kept as short and straight as possible, not exceeding 1.5 m in length.

For DC decouplers or VLDs used additionally for lightning protection, 3-10 kV/m can develop on the earth cable from a lightning surge and even shorter lengths shall be applied (< 0.2 m)[1)].

Cables (especially when underground) shall be installed inside a PVC conduit of suitable size.

The cable to zinc and cable to weld mesh connections shall use a suitably sized ferrule for crimping the cable connection to the weld mesh or to the exposed anode core wire of the zinc ribbon, soldering (using silver solder for copper cables or zinc-based solder for aluminium cables) and use of an approved, self-vulcanizing butyl rubber tape to cover the joint area.

For the cable to pipe connection, the pipeline is exposed by filing a small area of the coating down to bare metal and a M10 stud or bolt is welded to the pipe. The cable is terminated with a lug of suitable size and compatible material (copper lugs cannot be used with aluminium cable), crimped and fastened to the stud or bolt. The connection and exposed area is then covered with a rust-preventative coating or encapsulation.

The welding and re-coating method shall be suitable to the pipe’s wall thickness and coating material and shall be compliant with the PO’s cable attachment specification for the pipe type in question.

Note 1): If necessary, longer lengths are permitted with a co-axial cable/SPD arrangement - this significantly reduces the voltage drop compared to a normal earth cable (ref. DEHN’s application note for part SN4631).

B.6 Gradient control measures for valve chambers subject to vandalism

In areas prone to vandalism, a temporary connection upon entering a valve chamber shall be used. In this case, permanent cable connections and VLDs are not installed.

The gradient control mat or continuity ring is still equipped with a connector plate or earthing boss as shown in figs B.2 and B.3, and the pipe or valve is also equipped with a suitable connector plate or prong.

The connection shall be made with an insulated jumper cable with high current capacity and insulated handles. A car battery jumper lead rated 400 A or higher is suitable for this purpose. The connection shall be made to the structure side first and then to the pipe. Removal is by reverse order.

A clearly visible warning sign printed on a plastic backing shall be installed at the entry point (see fig B.4).

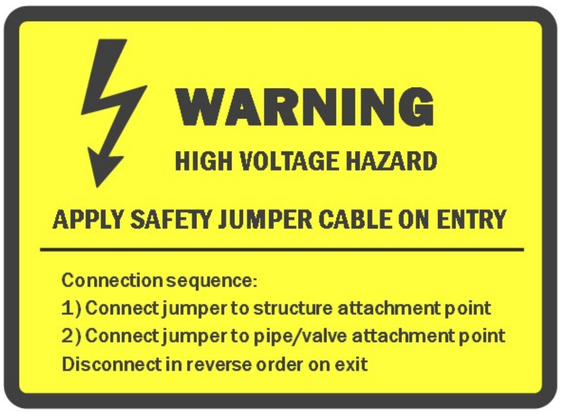


Figure B.4 – Warning sign for valve chambers without VLDs

Operation and maintenance manuals shall also give clear directions on this aspect.

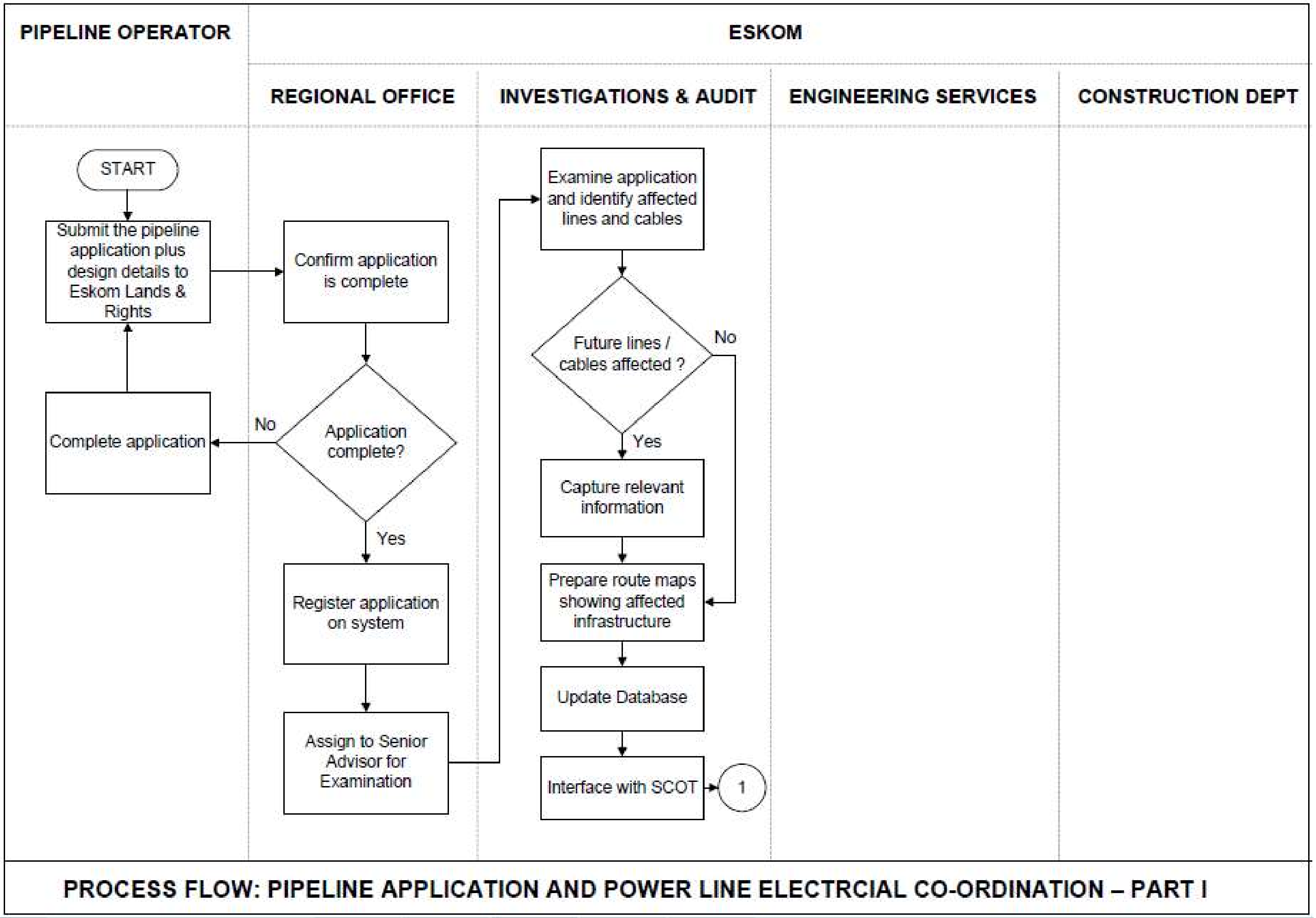
To further minimise the risk, exposed metallic components in the valve chamber may be coated with paint of high dielectric strength (e.g. acrylic/epoxy/enamel/urethane/silicone/parylene), mastic tape or composite shrouds.

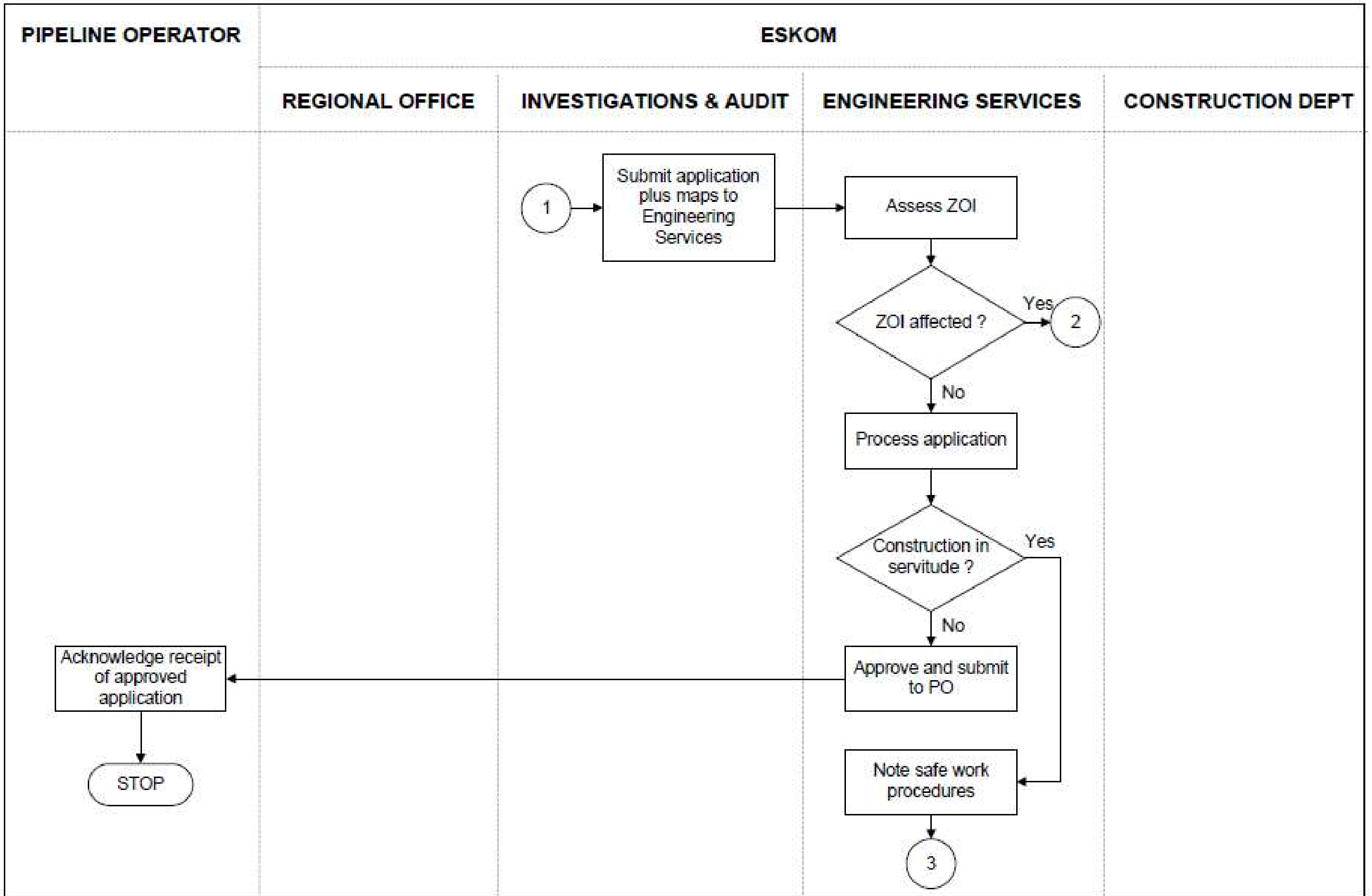
Where possible, non-metallic lids and lid seats should be used and steps and ladders removed completely, with maintenance personnel using non-metallic portable ladders instead.

This approach is not suitable for external gradient mats. If external protection is required, this should be provided using asphalt cover and/or by ensuring that any externally accessible metal that could be at pipe potential is covered with an insulating coating.

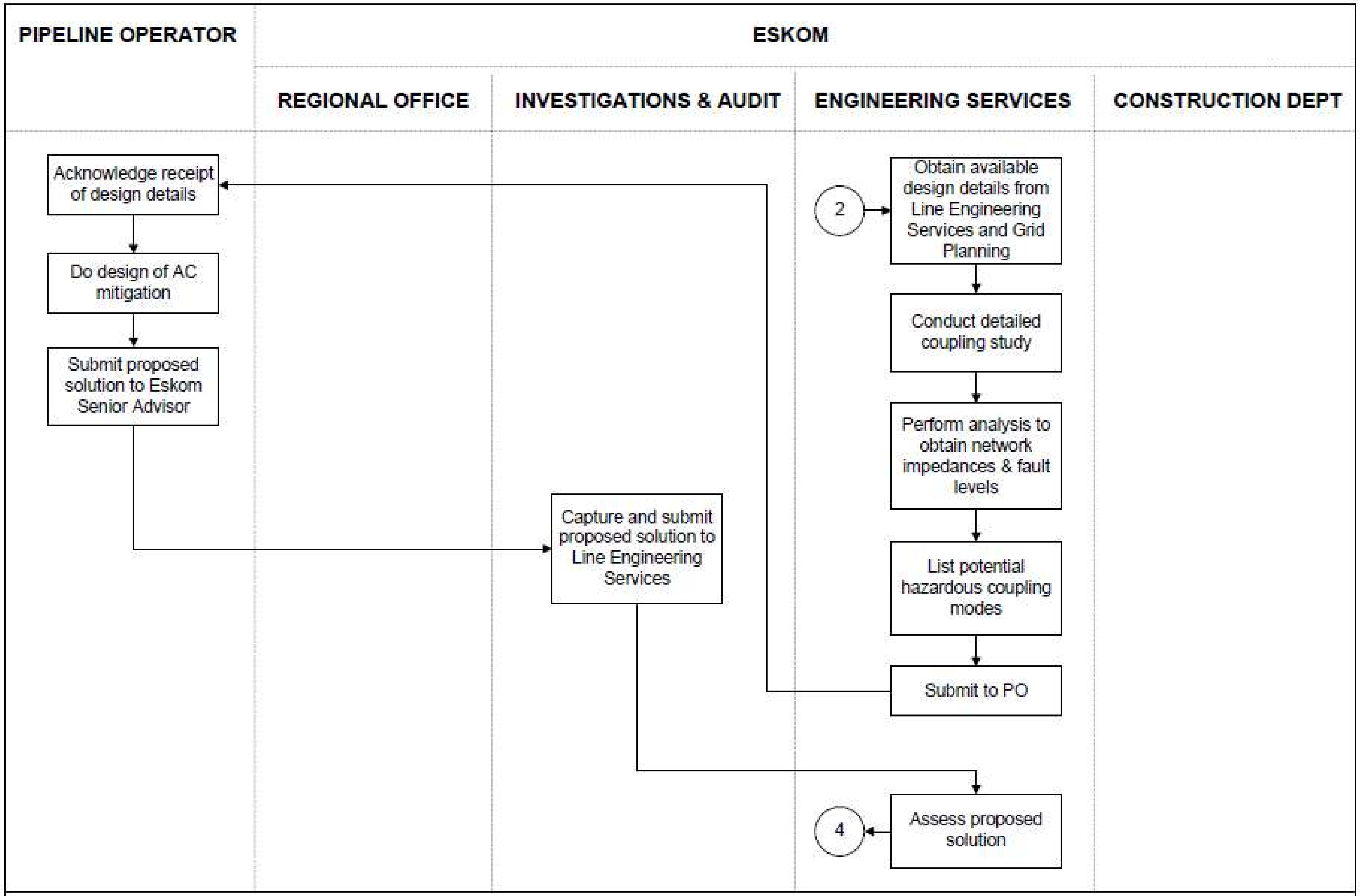
This approach shall be applied only as long as the risk of vandalism persists. Under normal circumstances, a permanent cable connection with a VLD is the preferred option, see par. B.3 - B.5.

Annex C - Flowchart

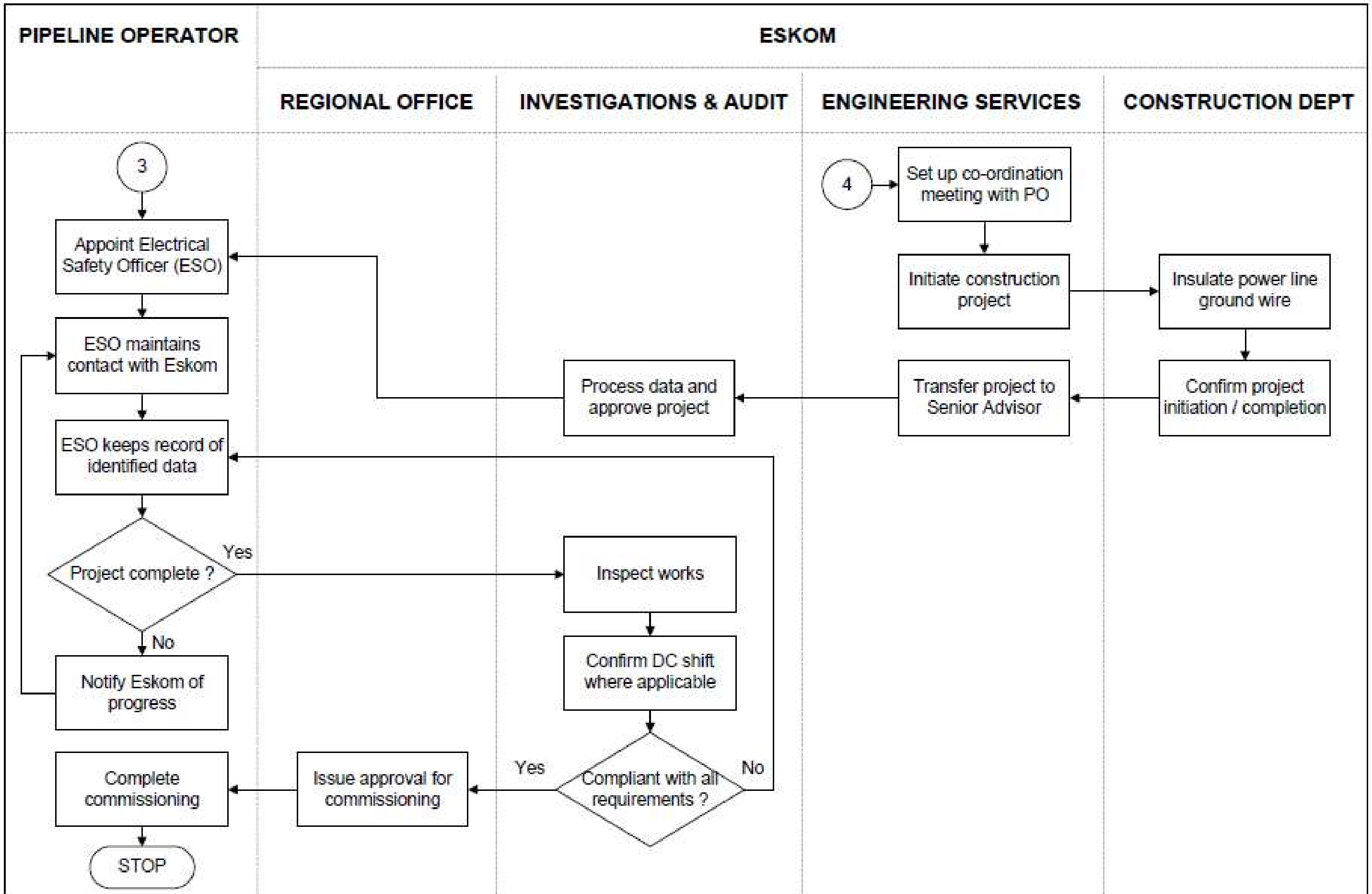




PROCESS FLOW: PIPELINE APPLICATION AND POWER LINE ELECTRCIAL CO-ORDINATION – PART II



PROCESS FLOW: PIPELINE APPLICATION AND POWER LINE ELECTRCIAL CO-ORDINATION – PART III



PROCESS FLOW: PIPELINE APPLICATION AND POWER LINE ELECTRCIAL CO-ORDINATION – PART IV

Annex D – Inspection sheet for a.c. mitigation components and servitude works

Inspection sheet No:	**Date of issue:**

Pipeline name and location: ....

Pipeline owner and address: ....

Contractor responsible for a.c. mitigation design: ....

Contractor responsible for a.c. mitigation installation: ....

INSTALLATION

☐ New installation on new pipeline	☐ New installation on existing pipeline	☐ Alteration / extension
Type of exposure:	☐ General Public	☐ Authorised personnel
Type of cathodic protection:	☐ Impressed current	☐ Sacrificial anodes
Type of pipeline product:	☐ Hazardous substance	☐ Non-hazardous substance

Name and voltage rating of power line(s) or cable(s) influencing this pipeline: ....

Owner and address of the power line(s): ....

Section of pipeline inspected: KP...................... – KP......................

Description of installation covered by this inspection (add additional pages or drawings as applicable):

....

....

Inspection sheet *(continued)*

NUMBER OF ITEMS COVERED BY THIS INSPECTION		
Item	**Existing installation**	**New / altered installation**
CP rectifier		
Vertical earth rod electrode		
Zinc ribbon electrode		
Gradient control mat		
d.c. decoupler		
Magnesium or zinc anode		
Surge protection or voltage limiting device		
Bonding link		
Drainage unit		
Earth cover around installations		
Rehabilitation of servitude		
Pipeline markers		
Power line tower earth wire isolation		
Power line tower sacrificial anode		
d.c. shift at tower footing		
Impressed current ground bed (location check)		
Maintenance schedule		

Inspection sheet *(continued)*

INSPECTION AND TESTS				
Inspection			**Existing installation**	**New / altered installation**
1 Accessible components correctly selected				
2 All protective devices of the correct rating				
3 Components have been correctly installed				
4 The enclosures used are of the correct IP rating				
5 Bonding links and cables of the correct thickness and length				
6 Components that may become “live” protected from direct contact (dead front construction)				
7 Components correctly labelled				
8 SANS 1014-1 Certificate of Compliance issued for the CP rectifier installations				
Tests	**Units**	**Instrument**	**Reading /result**	
			Existing installation	**New / altered installation**
1 Continuity of cables and bonding	Ohm			
2 Resistance of earth electrode (a.c. measurement)	Ohm			
3 Impedance of d.c. decoupler (below 15 V r.m.s. applied)	Ohm			
4 Pipeline voltage to remote earth	V r.m.s.			
5 d.c. potential shift at tower footing due to CP system	mV			

Inspection sheet *(continued)*

INSPECTION AND TESTS

Comments: ....

....

....

....

RESPONSIBILITY

I/We, being the person(s) responsible for the INSPECTION AND TESTING of the a.c. mitigation measures, particulars of which are given in this form, confirm that the installation conforms to the design requirements approved by the relevant Electrical Supply Authority and the Pipeline Operator. The extent of the liability of the signatory is limited to the installation described in this form.

Name (in block letters): ....

Capacity: .... Signature: ....

Address: .... Date: ....

....