

Australian/New Zealand Standard™

Electrical hazards on metallic pipelines



AS/NZS 4853:2012

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Australian Building Codes Board
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Consumers' Federation of Australia
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Australian/New Zealand Standard™

Electrical hazards on metallic pipelines

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-001, Wiring Rules, to supersede AS/NZS 4853:2000.

This revision was prepared to address experience gained with the implementation of AS/NZS 4853:2000.

This revision is a general revision of the Standard and introduces a risk based design approach to address electric shock hazard situations and respective mitigation methods.

The significant changes in this revision include—

- (a) the Standard has been restructured to improve its clarity;
- (b) a structured process to assess the likelihood of an electrical hazard being present on a metallic pipeline, and the methodology by which the risk level associated with the hazard is calculated, and the effectiveness of methods to reduce the risk to an acceptable or in the ALARP region to a tolerable level is provided;
- (c) a safety management methodology to document the assessment and control of electrical hazards is introduced, together with requirements for these to be reviewed at defined intervals to assure the ongoing effectiveness of the control; and
- (d) the appendices are revised and expanded.

This Standard has adopted the risk based assessment criteria developed by Energy Networks Australia and Electrical Engineers Association (New Zealand) to align the safety requirements of this Standard with those of the electrical power industry.

Symbols used in equations in this Standard are defined in relation to the particular equations in which they occur.

The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is only for information and guidance.

Statements expressed in mandatory terms in notes to tables are deemed to be requirements of this Standard.

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FOREWORD

The close proximity of high voltage power networks and pipelines can result in hazardous voltages on the pipeline. Electrical traction systems and lightning activity can also cause hazardous voltages in pipelines.

This Standard provides guidelines to calculate the magnitude of the electrical hazards, and to assess the effectiveness of methods used to mitigate the hazard. Because experience has shown that it may not be practicable to achieve specific voltage limits, the Standard has adopted a risk management based methodology that requires the application of physical and procedural controls that will reduce the risk to an acceptable level.

This Standard considers a number of circumstances that give rise to electrical conditions on pipelines—

- (a) low frequency induction (LFI) due to parallel or near parallel positioning of the pipelines and high voltage power lines or high voltage a.c. traction systems;
- (b) earth potential rise (EPR) due to pipeline proximity with high voltage power line towers, underground cable joint bays, substation earth grids, and other earthing current discharge points;
- (c) EPR due to lightning current following lightning strikes adjacent to pipelines;
- (d) the effects of lightning current introduced to the pipeline, directly or indirectly, and the effects due to the electrical properties of the pipeline and its coating;
- (e) capacitive coupling due to the placing, temporarily or permanently, of pipelines adjacent to high voltage power lines; and
- (f) the accidental contact of pipelines with other electrical systems such as electricity distribution or traction systems.

The electrical characteristics of the pipeline are always influenced by the properties of the protective coating applied to the external surface of the pipe and the effect of this coating must be considered in any analysis.

STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

Australian/New Zealand Standard
Electrical hazards on metallic pipelines

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard applies to metallic pipelines used for transmission and distribution of fluids, both buried and above ground. The responsibility for the application of this Standard rests with the owner, licensee or the operating authority of the pipeline.

This Standard sets down the minimum requirements for managing the safety of personnel working in the vicinity of pipelines and equipment installed on pipelines and specifically addresses the requirements for the control of electrical hazards on transmission and distribution pipelines.

The practical rules and guidelines also provide the basis for an engineering assessment by competent persons of situations that are not specifically addressed by the Standard.

This Standard describes the mechanisms that create hazardous electrical conditions on such pipelines and provides guidance on how to calculate and mitigate these hazards to minimize the risk of—

- (a) harm to people making contact with the pipeline including employees and the public;
- (b) damage to the pipeline coating and metal; and
- (c) damage to equipment such as the pipeline cathodic protection (CP) system and telemetry systems.

The risk management based methodology developed by the power industry for a similar purpose in power system earthing design has been adopted to provide a consistent approach to risk treatment for similar electrical hazards in the power and pipeline industries.

Guidance on the treatment of lightning strikes is also provided.

The Standard also recognizes that alternating currents may cause corrosion of metallic pipelines.

1.2 EXCLUSIONS

This Standard does not apply to pipes installed within a plant or processing environment, although some of the principles in the Standard may have application in the analysis of electrical hazards in these areas.

This Standard does not apply to an electrically powered plant used in the construction of pipelines.

This Standard does not address issues associated with static electricity generated by fluid flow. Control of static electricity is addressed in AS/NZS 1020.

1.3 RETROSPECTIVE APPLICATION

Publication of a new Standard or a new edition of a Standard does not of itself require modification of existing physical assets constructed to a previous Standard or edition of a Standard.

The requirements of this Standard shall apply to all new pipelines.

An existing pipeline that is redesigned, upgraded or which is subjected to a review of electrical hazards shall comply with the requirements of this Standard.

NOTE: Electrical hazard risk treatment designed to the previous version of this Standard is expected to comply with the requirements of this revision at the time of their design.

A review of electrical hazards to ensure compliance with the minimum requirements of this standard shall be programmed to be completed within a reasonable period that is commensurate with the perceived risk level.

1.4 REFERENCE DOCUMENT

The documents referred to in this Standard are listed in Appendix A.

NOTE: See the documents listed in the Bibliography for additional information.

1.5 DEFINITIONS

For the purpose of this Standard, the following definitions apply.

Where the terms voltage and current are used without further qualification, they imply r.m.s. values unless otherwise defined.

1.5.1 Accessible

Capable of being reached easily without climbing over or removing obstructions, or using a movable device such as a ladder.

1.5.2 Admittance (Y)

Describes a measure of the ease in which a circuit allows alternating current to flow.

It is the inverse of Impedance and is usually expressed in terms of conductance and susceptance e.g. $Y = G + jB$ siemens where G is conductance and B is susceptance.

The SI unit for Admittance is the siemens (S).

1.5.3 Anode

An electrode, placed in the electrolyte, to apply cathodic protection to a structure.

1.5.4 Approved

Approval by the Licensee (for pipelines complying with the AS 2885 series) or by the pipeline Owner or operating authority (for other pipelines), and includes obtaining the approval of the relevant regulatory authority where this is legally required. Approval requires a conscious act and is given in writing.

1.5.5 Appurtenance

An accessible accessory or adjunct to a pipeline, e.g. a valve or cathodic protection test point.

1.5.6 As low as reasonably practicable (ALARP)

A risk may be assessed as ALARP only if—

- (a) risk reduction is impracticable; or
- (b) if the cost of additional risk reduction is grossly disproportionate to the improvement gained.

1.5.7 Authorized person

The person in charge of the premises, or the person appointed or selected by the person in charge of the premises to perform certain duties associated with the pipeline.

1.5.8 Cathodic protection (CP)

The prevention or reduction of corrosion of metal by making the metal the cathode in a galvanic or electrolytic cell.

1.5.9 Cathodic protection unit

d.c. power supply controller for an impressed current cathodic protection system.

1.5.10 Clearing time (Primary)

Primary clearing time is the total time taken by the main protection system to detect and clear the fault. The primary clearing time is the value used for human safety calculations.

NOTE: Backup clearing time is the total time taken for the backup protection system to operate following initiation from the main protection system. It operates only if the main protection system has not cleared the fault.

1.5.11 Competent person

A person who has acquired through training qualification or experience or a combination of these, the knowledge and skills to perform the task required.

1.5.12 Counterpoise

An extension of the earthing system radiating from a substation or tower earthing system.

1.5.13 Coupling factor (see Figure 1.5)

The coupling factor (μ) is associated with underground power cables or overhead power lines. It indicates the proportion of the fault current flowing in that cable or line returning to its source of supply through associated metallic sheaths and screens of those cables or OHEW of lines.

It is expressed as the ratio of the vector sum of current returning via the metallic paths to total fault current flowing in that cable or line. It has a value between 0 and 1 where 0 means no current return and 1 means all current return via metallic paths.

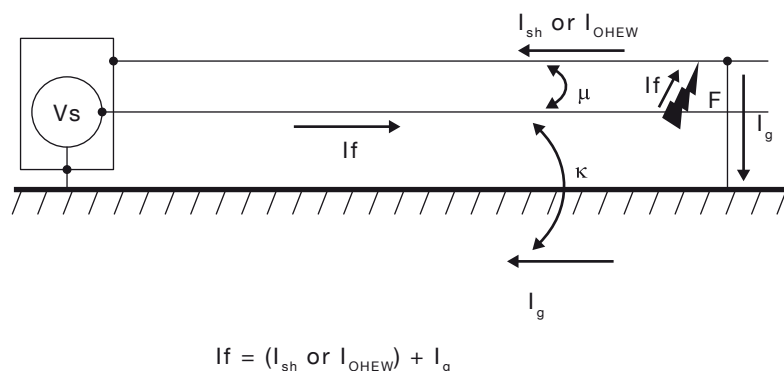


FIGURE 1.5 ILLUSTRATION OF COUPLING AND SHIELDING FACTORS

1.5.14 Diameter

The outside diameter of the nominated pipeline.

1.5.15 Drainage bond

A return conductor system allowing affected structures to return stray current to the traction rail.

1.5.16 Earth (noun)

The conducting mass of the general body of the earth.

1.5.17 Earth (verb)

To connect any conductor to earth.

1.5.18 Earth fault current

The current entering the ground at a particular location, taking into account the resistance of the earthing at that location.

1.5.19 Earth potential rise (EPR)

See Clause 3.2.

1.5.20 Electrode

An electronic conductor that allows current to flow either to or from an electrolyte with which it is in contact.

1.5.21 Electrolyte

A liquid, or the liquid component in a composite material such as soil, in which electric current may flow by ionic charge transfer.

1.5.22 Equipotential mats

A conducting metal mesh or structure at or below ground level at test points or other pipeline facilities and connected electrically to the pipeline, to avoid differences of electrical potential across the body of a person.

1.5.23 Exposure zone

Section of pipeline impacted by EPR or LFI.

1.5.24 Fluid

Any liquid, vapour or gas, or a mixture of any of these.

1.5.25 Hazard

A source of potential harm.

1.5.26 Holiday

Any flaw or discontinuity in a coating.

1.5.27 Impedance (Z)

Describes the measure of opposition of a circuit to alternating current flow and is usually expressed in terms of resistance and reactance e.g. $Z = R + jX$ ohms where R is resistance and X is reactance.

The SI unit for Impedance is the ohm (Ω).

1.5.28 Impressed current

Direct current supplied by an external power source to cathodically protect a structure.

1.5.29 Insulating joint

A joint that breaks electrical continuity in a structure, but does not affect the mechanical integrity of the structure.

1.5.30 Low frequency induction (LFI)

See Clause 3.3.

1.5.31 Licensee

The organization responsible for the design, construction, testing, inspection, operation and maintenance of pipelines and facilities. For pipelines that are licensed, the Licensee is generally the organization named in the pipeline licence issued by the Regulatory Authority.

NOTE: The Licensee generally applies to gas and liquid petroleum pipelines complying with the AS 2885 series.

1.5.32 May

Indicates the existence of an option.

1.5.33 Owner

The organization responsible for the design, construction, testing, inspection, operation and maintenance of pipelines and facilities.

NOTE: The term Owner generally does not apply to metallic pipelines that comply with the AS 2885 series.

1.5.34 Polarization cell

An electrochemical device that, at potential levels typical of cathodically protected structures, has low impedance to alternating current but high impedance to direct current of lower voltages used in cathodic protection systems. Some electronic devices that mimic the function of the electrochemical cells are also referred to by this title.

1.5.35 Prospective earth fault level

A theoretical maximum based on zero ohm impedance to earth at the point of fault.

1.5.36 Prospective step voltage

The voltage between two points on the earth's surface that are 1 m distant from each other. (1 m is considered to be the stride length of a person.)

1.5.37 Prospective touch voltage

The voltage between any metalwork and any point on the ground within a horizontal distance of 1 m of the metalwork, or between two conductive or semi conductive objects, when not being touched.

1.5.38 Protection measures (procedural)

Measures for protection of people or equipment from electrical hazards on a pipeline by way of process or procedures that will limit or minimize the likelihood of harm.

1.5.39 Protection measures (physical)

Measures for protection of people or equipment from electrical hazards on a pipeline either by physically preventing contact with the pipe or by providing permanent controls that reduce the voltage to safe limits.

1.5.40 Regulatory authority

An authority with legislative powers relating to pipelines, where such exist.

1.5.41 Risk

The effect of uncertainty on objectives.

Risk is often characterized by reference to potential events and consequences, or a combination of these.

Risk is often expressed in terms of a combination of the consequences of an event and the associated likelihood of occurrence.

(See AS/NZS/ISO 31000.)

1.5.42 Shall

Indicates that a statement is mandatory.

1.5.43 Shielding factor (refer to Figure 1.5)

The shielding factor (κ) is associated with underground power cables or overhead power lines. It indicates the proportion of the fault current flowing in that cable or line returning to its source of supply through the general mass of earth – ground return current.

It is expressed as the ratio of ground return current to total fault current flowing in that cable or line. It has a value between 0 and 1 where 0 means maximum shielding and 1 means no shielding.

It is related to Coupling Factor and can also be expressed as $\kappa = 1 - \mu$.

1.5.44 Should

Indicates a recommendation.

1.5.45 Step voltage (effective)

The voltage between two points on the earth's surface that are 1 m distant from each other while a person is making contact with them.

NOTE: The circuit is loaded by the human body impedance (typically 1000 Ω) when measured with a high impedance voltage meter.

1.5.46 Structure

A metal surface in contact with an electrolyte, usually being a pipeline and its ancillary fittings.

1.5.47 Test point

A nominated point on a structure (pipeline) for electrical contact.

1.5.48 Touch voltage (effective)

Defined in AS/NZS 3000 as the voltage appearing between simultaneously accessible parts.

In the context of this Standard the effective touch voltage is that appearing between accessible metalwork and a point on the earth's surface (or other accessible metalwork) separated by a distance equal to a person's normal maximum horizontal reach (approximately 1 m), loaded by the human body impedance (typically 1000 Ω) when measured with a high impedance voltage meter.

1.6 SYMBOLS AND UNITS

Symbols and the associated units are defined in the context in which they are used.

1.7 ABBREVIATIONS

a.c.	Alternating current
CP	Cathodic protection
d.c.	Direct current
DCVG	Direct current voltage gradient
EEA	Electrical Engineers Association (New Zealand)
ENA	Energy Networks Australia

EPR	Earth potential rise
LFI	Low frequency induction
MEN	Multiple earthed neutral
MIJ	Monolithic insulating joint
OHEW	Overhead earth wire
PPE	Personnel protective equipment
SPD	Surge protection device
SWER	Single wire earth return

SECTION 2 SAFETY

2.1 GENERAL

The risk from identified electrical hazards (including lightning) to personnel and equipment shall be reduced to an acceptable or in the ALARP region to a tolerable level. When physical controls are unable to reduce a voltage from an identified hazard to a safe level, additional risk treatment methods shall be applied until the risk is reduced to a tolerable level.

Each electrical hazard to personnel and the pipeline shall be identified (see Section 3) and controls shall be applied. These shall be documented in an electrical hazard management plan.

The design and risk management of electrical hazards shall be validated by a safety management study workshop comprising representatives of identified stakeholders.

The requirements are—

- (a) for pipelines designed, constructed and operated in accordance with the AS 2885 series, the effectiveness of the risk treatment shall be considered as part of the safety management study required by that Standard;
- (b) for pipelines designed, constructed and operated in accordance with another Standard the effectiveness of the risk treatment shall be considered in accordance with the requirements of that Standard; or
- (c) where none exists, in accordance with the requirements of this Standard.

The electrical hazard management plan shall be revised to reflect the requirements of the workshop, and—

- (i) for pipelines designed and operated to the AS 2885 series, incorporated in the pipeline management system; or
- (ii) for other pipelines, in the pipeline safety and operating plan.

The design shall be approved.

For consistency with the management of similar electrical hazards in the electric power industry this Standard has adopted the risk management based methodology developed by the Energy Networks Association (Australia) and the Electrical Engineers Association (New Zealand) for use applying this Standard in Australia and New Zealand respectively. This will provide a common approach for assessing the risk reduction contribution of identified controls applied to identified risk sources, and will result in similar safety standards being applied to similar hazards in the power and pipeline industries.

Electrical hazard risk management is an ongoing process over the life of the pipeline and risk treatments require continuous management so that they remain effective. The hazard management plan shall be reviewed periodically to identify changes in the pipeline or power line that may change the electrical hazard and, if necessary, to revise the treatment design.

The electrical hazard risk management plan shall specify the maximum review period. The period shall not exceed 5 years unless approved.

2.2 RISK CONTEXT

Where it is possible for an electrical hazard (voltage) to exist on a metallic pipeline, this Standard requires the risk to people and equipment to be evaluated, and treatment applied to reduce the risk to a tolerable level.

The Standard nominates a method for calculating the risk level, and the risk reduction achieved by known treatment measures. This provides a relatively easy-to-use method of assessing the effectiveness of risk treatments by individuals who are not necessarily risk specialists, and is provided so that there is consistency across the industry in the application of the Standard, and consistency with the management of similar hazards in the electric power industry.

The management of electrical hazards on metallic pipelines is a component of the overall design and safety of a metallic pipeline.

It is expected that the context for risk identification and management undertaken in accordance with this Standard will be established by the overall safety management system implemented by the Licensee or Owner of the metallic pipeline, and the work will be undertaken as a component of the safety and risk management analyses undertaken for the project during its initial design and once commissioned, through its ongoing operation.

For pipelines complying with the AS 2885 series, the risk management undertaken in accordance with this Standard is required to be considered in the Safety Management Study undertaken in accordance with the AS 2885 series, and Approved by the Licensee.

For water and other pipelines complying with another Standard, the risk management undertaken in accordance with this Standard is required to be considered in accordance with Safety Management Studies undertaken in accordance with the requirements of the design Standard, or of the Owner or Regulator, as applicable.

NOTE: ENA document EG-0 defines a framework within which the risk management should be undertaken, in accordance with this Standard.

2.3 ASSESSMENT AND MANAGEMENT OF ELECTRICAL HAZARDS

Electrical hazards and associated risk shall be controlled through the application of risk treatment methods.

The hierarchy of control methods to mitigate electrical hazards is as follows:

(a) *Elimination*

Remove the hazard completely (i.e. re-route the pipeline away from the power line).

(b) *Design and physical controls*

Use design features to prevent personnel contacting a pipeline with an electrical hazard (i.e. fences and barriers, buried pipelines, ground materials), or to permanently mitigate the hazard (e.g. earthing devices, equipotential mats, Faraday cage, warning marker signs).

(c) *Procedural controls*

Use PPE, warning signs and operating procedures for planned contact with pipelines with a potential electrical hazard.

Electrical hazards existing on the pipeline, pipeline stations, pipeline facilities and control systems shall be considered.

2.4 RISK ASSESSMENT

This Standard allows the quantitative assessment of control measures applied to reduce the risk from identified electrical hazards on metallic pipelines to a tolerable level. It provides a structured process for hazard identification, evaluation, control and where required, risk evaluation and management.

The risk management process shall involve—

- (a) collection of timely and relevant data;
- (b) performing calculations or simulations based on the collected data;
- (c) thorough analysis of predictions made and where required additional data and analysis;
- (d) implementation of actions indicated by the conclusions drawn; and
- (e) complete documentation of the assessment process for future review.

The pipeline Licensee or Owner shall undertake the Safety Management assessment of a pipeline. An electrical hazard management plan shall be prepared following this study to document the controls applied to each identified hazard to reduce the risk from it to personnel and equipment to an acceptable level.

The Standard recognizes that—

- (i) the hazards may be present during construction, general operation, and maintenance activities;
- (ii) the owners and operators of a pipeline asset may change over time; and
- (iii) the design considerations contributing to the electrical hazard status of a pipeline may change over time, for example due to the upgrade of an existing power line, or the installation of a new power line in the proximity of an existing metal pipeline.

The electrical hazard management plan shall be communicated to personnel involved in the construction, commissioning, operation, and maintenance of the pipeline.

The risk assessment process is described in Section 4 for Australia and Section 5 for New Zealand.

2.5 EFFECTIVENESS OF RISK TREATMENTS

The electrical hazard risk management plan shall include procedures for actively testing and assessing the operation and effectiveness of the earthing systems at the time the system is commissioned, and ongoing throughout the life of the installation.

The effectiveness of risk treatments shall be assessed at intervals not exceeding 1 year.

Deviations from risk treatment performance shall be reported to a safety representative and reviewed for remedial actions. The status of all risk treatments shall form part of the pipeline safety management review.

2.6 CONSTRUCTION SAFETY

Electrical hazards may exist during pipeline construction activities.

A study shall be undertaken as required to identify the hazards at each point along the construction site, and appropriate controls developed and implement. The risk treatment of identified hazards shall comply with this Standard.

The controls shall be incorporated in the construction safety plan.

NOTE: Minor construction activities undertaken by the Licensee and some maintenance activities may require specific analysis and control.

SECTION 3 ELECTRICAL HAZARD SOURCES

3.1 GENERAL

This Section describes the most common electrical hazard risk sources encountered on metallic pipelines.

There are a number of electrical sources that may create a hazard on a pipeline using a number of different mechanisms to transfer electrical energy to the pipeline. This section describes those sources and mechanisms that, if not controlled, may create an electrical hazard on a pipeline.

Each pipeline shall be assessed during design and throughout its operating life, to identify all sources of electrical hazard and to reduce the risk to personnel and equipment to a tolerable level.

The sources and consequences of electrical hazards may change throughout the operating life of a pipeline.

Figure 3.1 illustrates the process by which a source of electricity (a risk source), proceeds through various mechanisms to affect a buried metallic pipeline, resulting in a hazard to pipeline operating and maintenance personnel, the public, or equipment attached to the pipeline. Sections 4 and 5 describe the process by which the risk level is calculated, and the risk treatments applied to reduce the risk to a tolerable level.

Appendix M contains information on the electrical infrastructure that can give rise to electrical hazards.

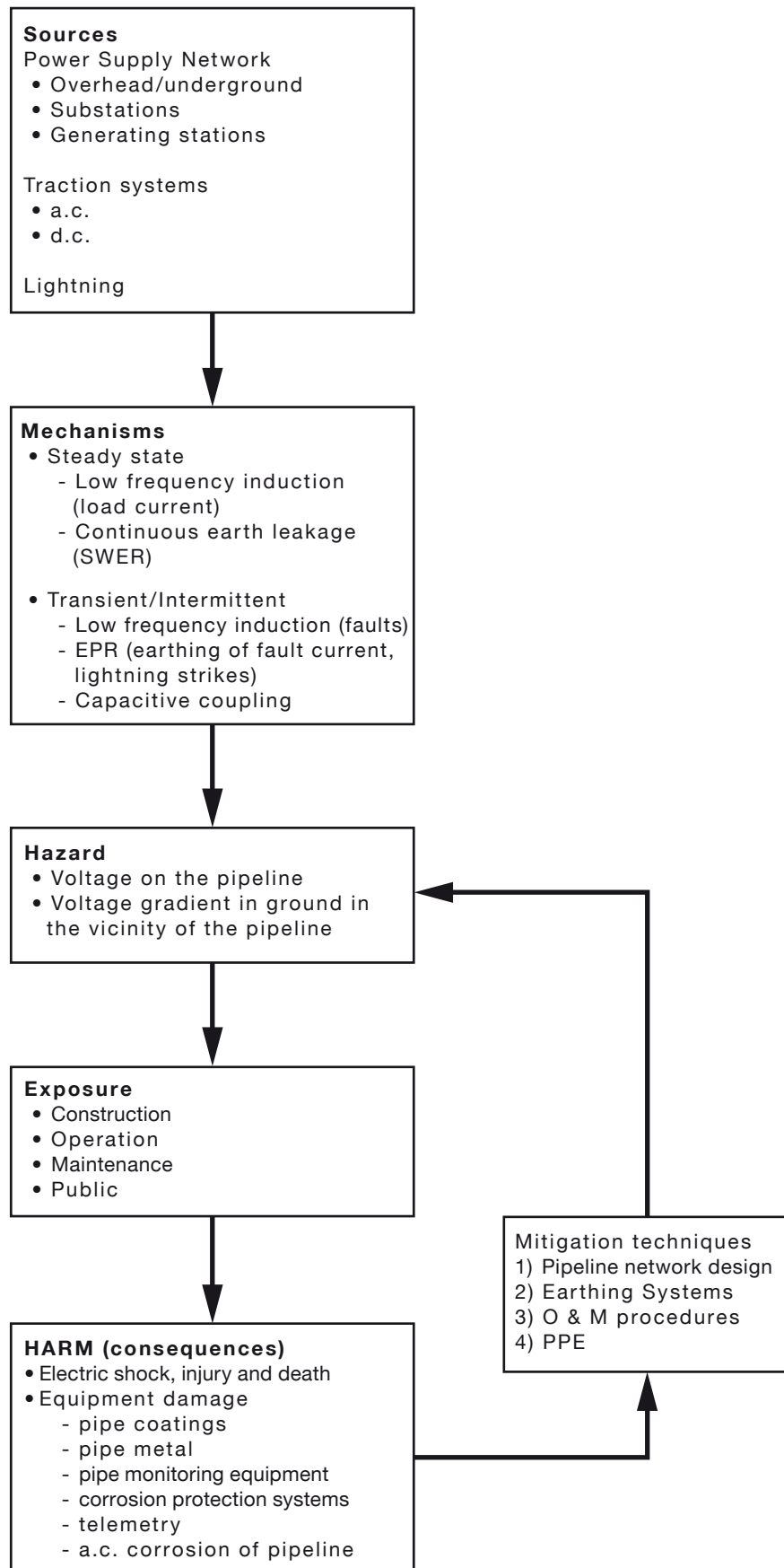


FIGURE 3.1 ILLUSTRATION OF THE PROCESS BY WHICH A SOURCE OF ELECTRICITY BECOMES AN ELECTRICAL HAZARD TO BURIED METALLIC PIPELINES

3.2 EARTH POTENTIAL RISE (EPR)

Earth Potential Rise (EPR) is caused by electrical faults that occur at electrical substations, power plants, or high-voltage power lines. The fault current flows through the structure or equipment and into the earth at the fault point and returns via the earth to the neutral point of the power source. The resistance of the earth is finite, so current injected into the earth at the grounding electrode produces a potential rise with respect to a distant reference point (remote earth).

This potential with respect to remote earth is highest at the point where current enters the ground, and declines with distance from this entry point. EPR is a concern in the design of electrical installations because the high potential may be a hazard to people or equipment. The potential gradient (drop of voltage with distance) may be so high that a person could be injured due to the voltage developed between two feet, or between the ground on which the person is standing and a metal object. Any conducting object connected to the electrical installation via the earth rails, fences, or metallic pipelines, may also be energized to the ground potential. This transferred (conducted) potential is a hazard to people and equipment outside the substation.

The magnitude of EPR voltage is simply the product of the current entering the ground at the earth electrode and the earth resistance of that electrode. If however, an alternate electrical path in the form of an overhead earth wire or underground cable screen is connected to the electrode and the source substation earth grid, there will be a split in fault current. This will result in a portion of the fault current return to the source via the electrical equipment (OHEW or cable screen) and the remainder through the earth electrode. The remaining percentage of current flowing into the earth is the only amount that will result in an EPR situation.

Current splitting gives the conductive component of the earth fault return current whereas the inductive component contributes to a shielding effect on the earth fault current. The current splitting due to alternate electrical paths and shielding effect from the alternate electrical paths effect are separate phenomenon and must be treated appropriately for a correct determination of the EPR and LFI values respectively.

NOTES:

- 1 Guidance on the treatment of EPR is provided in Appendix G.
- 2 In the case of a cable screen connected to the source substation, the current split can be 90/10 between cable screen and ground. In the case of an OHEW connected to the substation the current split can be 50/50. The power network should be considered in more details in relation to alternate return paths.
- 3 A sample calculation for a phase to earth fault on a 50 Hz high voltage installation is shown in Appendix G for an overhead line and cable network.

3.3 LOW FREQUENCY INDUCTION (LFI)

3.3.1 General

Alternating current on a high voltage power line can induce a voltage on an adjacent pipeline. This induction results in a voltage over the exposure length due to the electromagnetic field from the current. The induction is caused by the alternating magnetic field intersecting the pipeline, causing the pipeline to act as the secondary of an air core transformer. The voltage is proportional to the length exposed to the magnetic field. The effect applies to both buried and above ground pipelines.

Unlike the electricity supply, the induced voltage is not a voltage to earth. It does have a relationship to earth due to the electrical capacitance caused by the coating on the pipeline allowing some current to flow to earth along its length. This capacitive reactance depends on the wall area of the pipe and the thickness and dielectric constant of the coating material, and is greatly influenced by the properties of the pipeline backfill. Very dry sand for

example, increases the reactance, whereas electrolyte around the pipe reduces it towards the minimum represented by the coating alone. Values of from 1 to 10 microfarads per kilometre are not unusual. This corresponds to a reactance of approximately 3000 to 300 Ω , pipe to earth per kilometre at 50 Hz.

The earth path via this capacitive reactance may represent a personnel hazard in its own right if a very large LFI fault voltage is involved.

Figure 3.2 shows a power line adjacent to a pipeline:

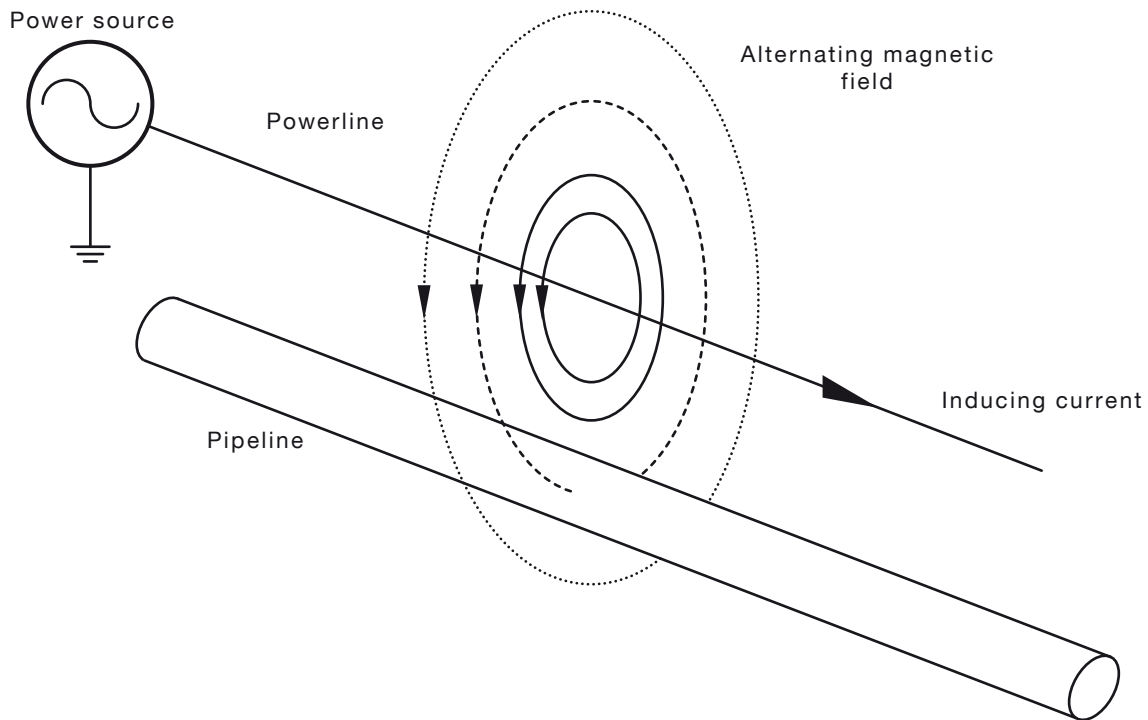


FIGURE 3.2 (a) ILLUSTRATION OF THE LFI MECHANISM

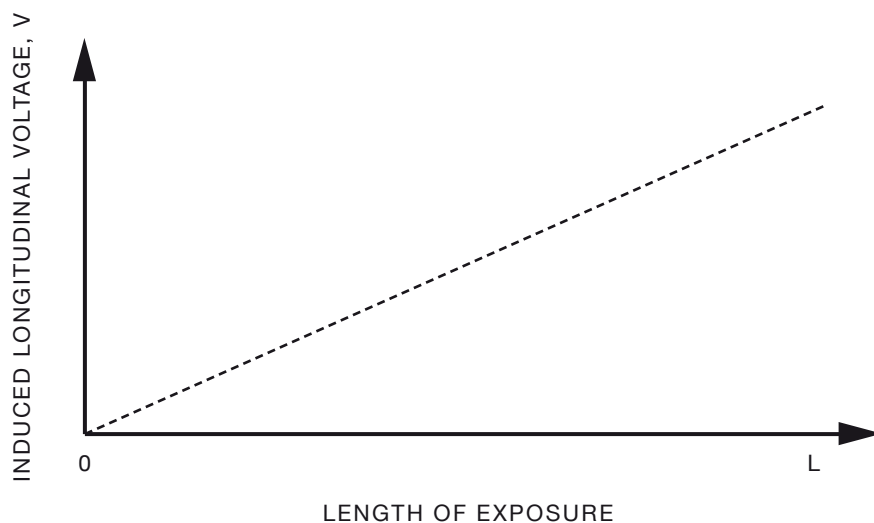


FIGURE 3.2 (b) INDUCED LONGITUDINAL VOLTAGE IN A PARALLEL PIPELINE WITH ONE END BONDED TO EARTH AND THE OTHER ISOLATED FROM THE EARTH

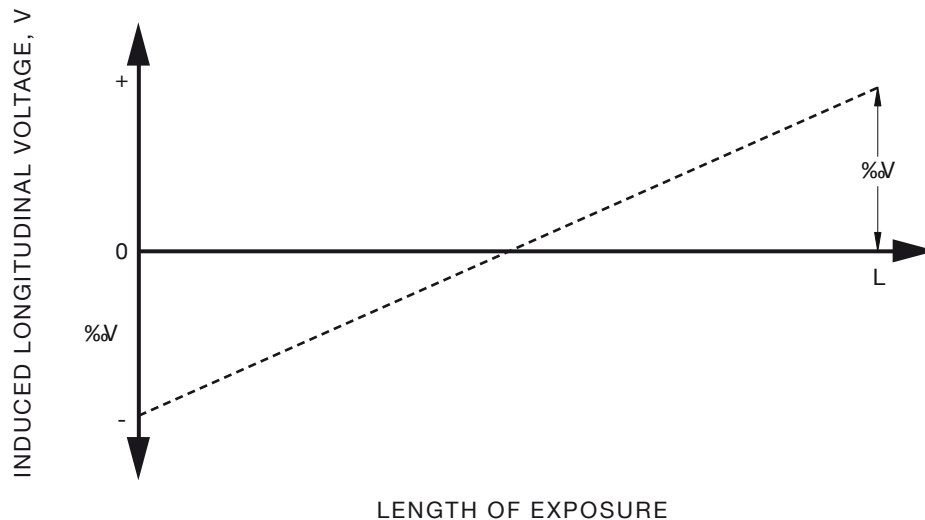


FIGURE 3.2 (c) INDUCED LONGITUDINAL VOLTAGE IN A PARALLEL PIPELINE WITH BOTH ENDS OF THE PIPELINE SECTION ISOLATED FROM THE EARTH

3.3.2 LFI mechanisms

3.3.2.1 Load current LFI

At normal operating currents, LFI will induce a voltage in a pipeline when it is in close proximity to a high voltage power line. The induced voltage will exist while the power line is in operation.

The induced voltage is the vector sum of the voltage induced by each power line phase current.

The magnitude of the induction is dependent on both the magnitude of the load current and the relative distances between each of the phases and the pipeline. Since the high voltage power line load current can be considered as a balanced set of currents in the three-phases, in which case their vector sum is zero, the LFI at design load conditions is always much less than the LFI under fault conditions.

The phase configuration on a high voltage power line can significantly increase the magnitude of the induced voltage compared with the configuration on lower voltage distribution lines.

Generally, as the power line voltage is increased, the distance between phases will be increased, resulting in an increase in the induced voltage.

The induced voltage is normally small, but in long parallels, and for high or unbalanced load currents, it can result in significant voltages.

NOTE: A sample calculation for load current LFI is shown in Appendix B.

3.3.2.2 Fault current LFI

Large currents will flow from the power line to earth during an earth fault, and can induce a large voltage on an adjacent pipeline.

Where the fault results in unbalanced currents, the combination of the fault current and the unbalanced current will combine to significantly increase the induced voltage on an adjacent pipeline.

NOTE: A sample calculation for fault current LFI is shown in Appendix C.

3.3.2.3 *A.C. traction LFI*

The effect of a.c. rail traction is similar in its induction effects to fault current induction.

There are two significant differences as follows:

- (a) The initiating current has a variable location, due to the traction car movement.
- (b) The current varies with the degree of acceleration of the car.

Item (b) is caused by variation in the a.c. waveform to provide greater or lesser acceleration. In addition, this can give rise to a rich source of harmonics in the power system. This may increase the peak voltage induced on the pipeline and may impact some pipeline telemetry systems.

NOTE: Calculation of LFI voltage on a pipeline subject to the foregoing condition is difficult. Guidance is given in Appendix D. Several different power arrangements may exist in the traction system. They include the following:

- (a) Booster transformers (BT), whereby rail current is 'collected' by transformers at about 3 km intervals, and returned by non-earthed conductors.
- (b) Auto-transformers (AT), whereby higher powered auto-transformers supply rail current at about 10 km intervals.
- (c) Direct feed, with no correction effect on rail return.

3.4 CAPACITIVE COUPLING

Capacitive coupling applies to any metal object in the electric field that is isolated from earth.

Capacitive coupling is the condition whereby the capacitance between the phase conductors or any metal object forms an electrical path to earth. The pipeline voltage is proportional to the voltage of the power line and the ratio of the capacitances between each object.

A small current flows continuously in this way, distributed along the transmission line. The interposition of a metallic object, such as a length of pipeline suspended above the earth, in the vicinity of the lowest conductor, will intercept a portion of this current (typically 5% to 10%), and conduct it to earth either by metallic contact of tracked vehicles or by its own capacitance to earth if the mechanical handling vehicle has rubber or similar insulating tyres.

In the event of a vehicle with insulating tyres being used, a person in contact with earth and with the vehicle will cause the current to flow through the body to ground because the body has a lower impedance than the pipe capacitance.

To determine the effect on personnel, the effect of capacitance current for a suspended pipe length should be used.

NOTES:

- 1 A sample calculation is shown in Appendix F.
- 2 There is no (or possibly a small) capacitive coupling between an overhead line and a buried pipeline. Above ground pipes are affected by capacitive coupling — especially during installation.

3.5 EFFECTS OF LIGHTNING

3.5.1 The electrical nature of lightning

Lightning may range from a small amount with a charge of less than 1 coulomb up to, in rare cases, over 200 coulombs. These are small quantities, but the charge is delivered in a few microseconds, at voltages over 100 000 000 V and peak currents ranging from several thousand amperes to over 200 000 A. The concept of the peak energy (volts by amperes by time) is difficult to grasp because of the magnitude.

The current is so large and the electrical pressure driving it so immense that the only practicable protection solution is to accept the charge via an earthing system and to conduct it by as short a path as possible to earth. If this path is too tortuous, or too long, or the resistance of the earthing system too high, a very large voltage is developed between the earthing down conductor (or structure) and all surrounding earthed objects. This leads to a secondary or side flash from the down conductor to nearby objects. This side flash is often the source of pipeline lightning problems.

A direct strike to a pipeline would destroy part of any pipe coating in its path to earth. It might also cause metal damage to the pipe itself through gross overheating of the pipeline at the entry or exit points. These are rare conditions.

The side flash energy is of much lower value than a direct strike to the pipeline. The side flash presents a parallel path to the direct strike to ground away from the pipeline and the pipeline's electrical properties need to be considered to determine the effects.

3.5.2 The electrical properties of coated pipelines

A modern high-performance pipeline coating has very effective electrical insulation properties. A near holiday-free coating has an insulation resistance to ground in the order of MΩ/km and a high voltage withstand capacity. However, in practice the coating may have varying degrees of defects which expose the steel of the pipeline. A high-quality pipeline coating of 1 mm thickness has a voltage withstand capacity in the order of several tens of thousands of volts.

The presence of insulating or dielectric material produces an electrostatic capacity (capacitance). This property stores electrical energy in the dielectric itself. The value of the capacitance will depend on the area of pipe surface, the thickness of the coating and its dielectric constant.

A value of capacitance in the order of 1 to 10 microfarads per kilometre of pipeline may be expected. However, the precise value of this is modified by the effect of very dry backfill, which increases the thickness of the dielectric material, thus reducing the capacitance.

A pipeline is very different to other structures in its behaviour on receiving lightning flash current. The pipe is essentially a very long capacitor that, when covered with most modern coatings, can withstand very high voltages. The capacitance of the pipeline can be calculated as follows:

$$C = K\epsilon_0 \frac{A}{S} \quad \dots (1)$$

where

- C = capacitance (farad)
- K = dielectric constant (approximately 2.2 for a typical coating)
- ϵ_0 = permittivity of free space (8.85×10^{-12} farad/metre)
- A = surface area (m^2)
- S = coating thickness (m).

3.5.3 The combination of lightning current with the pipeline

Lightning current or its resultant effects can enter the pipeline in several ways. These include the following:

- (a) By a direct flash strike to a buried metallic pipe if there are no objects that provide a more conductive path to earth.
- (b) By a direct flash strike to above ground pipe or ancillaries (including valves, valve spindles, CP test points, CP units, pump stations, scraper stations, telemetry installations).
- (c) By lightning electromagnetic pulse (LEMP), from a lightning strike direct to earth some distance from the pipeline.
- (d) By conduction, through the earth, following a lightning strike to some adjacent tree, structure or equipment not directly connected to the pipeline. Conduction of current through the earth and the earth resistance produces a voltage rise called earth potential rise (EPR). EPR is also produced by direct lightning strikes, over or near the pipeline, to the earth.
- (e) By shared flash conditions with some other structure that is essentially earthed, but which has metallic connection to the pipeline. For example, electrically powered equipment, such as CP converters, or pump station equipment or telemetry equipment, will receive substantial current from a lightning strike to the low voltage power lines serving this plant. The connection to the pipeline will cause a Kirchhoff division of current, depending on the respective surge impedances.
- (f) By a side flash, which is the process by which some earthed object (tree or structure) suffers a lightning strike then re-transmits a portion of the lightning current by an arc to the adjacent pipeline.

The incidence of direct lightning strikes is relatively rare; it ranges from 2 to 10 strikes/1000 km/annum depending on lightning counts for the location. The incidence of longitudinal induction is around 100 times greater due to the 'catchment' area being much greater, in the order of ± 0.5 km from the pipeline. EPR episodes may be considered as about 10% of the lightning electromagnetic pulse (LEMP) incidents in number.

3.6 OTHER HAZARDS

3.6.1 Open-circuited neutrals

Metallic water services are normally connected to the electrical installation earth bar and then to the neutral bar (via the MEN link) at all premises, via equipotential bonding arrangements in accordance with AS/NZS 3000. This means an open circuit neutral conductor may cause a rise of voltage on the water services system that exceeds acceptable limits determined in Sections 4 and 5.

This condition is caused by an equipment fault occurring on the electricity installation, and is not subject to any controls except by isolation of the water pipes. The pipeline owner should consider this risk.

Water supply pipelines are often isolated from water services and thus this risk may not be transferred.

NOTE: Water services are the consumer's connection to the water pipeline

3.6.2 D.C. traction systems

3.6.2.1 General

Pipelines in urban areas often cross or are buried alongside railway tracks that carry the return current from d.c. traction (rail) systems.

Drainage bonds designed to mitigate the effects of traction return currents on pipeline CP systems bring conductors from the pipeline and the rail into contact via control equipment.

Although the drainage bonds are enclosed and are thus protected against accidental contact, this does not exclude the possibility of personnel working on the pipeline CP system being exposed to the rail potential referenced to the pipeline.

NOTES:

- 1 Voltages in the order of 150 V d.c. may occur for a significant time and higher voltages may be present for short durations.
- 2 The calculation of rail voltage requires considerable knowledge and experience in electrical d.c. traction systems.

3.6.2.2 Voltage exposure

Hazardous voltages may appear from time to time in and around CP drainage bonds between the following three structures:

(a) *The pipeline connection*

The pipeline connection will conduct any potential that exists on the pipeline to the drainage bond.

(b) *The rail line connection*

The rail line connection will conduct any rail potential to the drainage bond. In the absence of any concurrent dangerous electrical condition on the pipeline, the pipeline potential will be close to the local earth potential, and the two may (for the purpose of this analysis) be considered to be equipotential.

Voltages on the rail result from the return currents of the traction system. Typically, the voltage is within ± 70 V d.c. of earth, but can rise due to faults.

Details of the voltages present on a traction system shall be obtained if required for risk assessment and risk treatment design.

(c) *The local earth*

The local earth may be subject to EPR.

With a supply of 1500 V d.c. at many hundreds of amperes, d.c. traction systems have the potential to impose hazardous voltages on rail tracks.

In the context of pipelines, this appears to be only a hazard to personnel with access to CP drainage bonds, where the potentials on the pipeline, earth and rail are accessible.

NOTE: Electrical potentials on the rail are monitored by automatic systems that will earth the rail should they become hazardous. In addition, other systems will isolate the electrical supply in case of train faults, which will in turn reduce the rail-earth potential to zero.

The automatic systems will not necessarily protect against intermediate level potentials that can cause noticeable but reversible physiological effects. These potentials should be dealt with by using proper operating procedures (e.g. gloves, or instructions to not touch two structures simultaneously).

3.6.3 A.C. traction systems

A.C. traction systems are a source of electrical hazards. Appendix D provides information on these systems.

3.6.4 Storage and handling of pipe lengths in proximity to powerlines

During construction and maintenance of pipelines with coated surfaces in close proximity to high voltage power lines it may be necessary to—

- (a) use mechanical handling equipment;

- (b) store pipe lengths;
- (c) connect long strings of pipe lengths during construction;
- (d) remove pipe lengths during maintenance; and
- (e) physically touch uncoated parts of pipe lengths.

This may result in exposure to electrical hazards due to excessive induced voltages or mechanical handling equipment touching overhead conductors.

Where conductors are used to earth pipe lengths or bond between pipe lengths during construction and maintenance, they shall not be less than the equivalent of 2 by 16 mm² copper conductors in parallel.

NOTE: Guidance on the handling of pipe lengths and the use of PPE such as insulating gloves, insulating footwear and equipotential mats is given in Appendix H.

3.7 INTERACTION BETWEEN PIPELINE PROTECTIVE EARTHING SYSTEMS AND CATHODIC PROTECTION SYSTEMS

Under normal operating conditions pipelines may be electrically isolated from their earthing systems in order to maintain cathodic protection (CP) potentials. During fault conditions the pipeline must be electrically connected to the earthing systems to mitigate electrical hazards.

NOTE: For information on CP systems, see AS 2832.1.

Earth bonds are normally isolated by d.c. blocking devices which isolate the CP current from the earth during normal operation, whilst allowing higher d.c. voltages and a.c. voltages to pass to earth when required.

The designer shall consider the following issues:

- (a) Failure of an isolating device can cause a loss of CP or loss of earth connection.
- (b) Normal operation of the device may interfere with the successful performance of some pipeline testing methods. For example during coating defect surveys the boosted CP current may cause the surge device to conduct indicating coating defects at each device.

Disconnection of the devices will manage Item (b), but will expose personnel and equipment to the original electrical hazard.

There are a variety of d.c. blocking devices that may be used, each with its own characteristics. Their electrical properties shall be considered when selecting the equipment and when developing and implementing pipeline operating and testing procedures.

The following typical properties shall be considered:

- (a) Breakdown voltage.
- (b) Cable impedance.
- (c) Reaction time.
- (d) Number and duration of fault events.
- (e) Intrinsic safety if required for hazardous areas.
- (f) Forward and reverse d.c. conduction voltage.
- (g) Current carrying capacity (a.c. and d.c.; continuous, power surge and lightning).
- (h) Effect of temperature.
- (i) Safety.
- (j) Maintenance.

- (k) Integrity testing.
- (l) Firing and quenching voltage.

All of these may have an affect on actual cathodic protection levels or on measurement of cathodic protection pipe to soil potentials.

Information on interaction between protective earthing systems and CP systems is given in Appendix I.

Magnesium anodes should not normally be used as earthing because of their high corrosion rate and possible a.c. rectification which could render the anode ineffective.

3.8 PIPELINE CORROSION RESULTING FROM STEADY STATE LFI

Until relatively recently it was generally assumed that alternating currents induced on a steel pipeline were not capable of producing measurable corrosion. However, in recent years several papers have been published that report significant pipeline corrosion caused by alternating currents. This appears to result in part from improved coating quality and increasing interaction between pipeline and power transmission infrastructure that results in high current densities at small coating defects.

Published guidance on acceptable voltage levels can be found in CIGRE TB 290 and in EN 15280.

The steady state induced voltage limit stated in these documents is—

- (a) 4 V a.c. for soil resistivity $\leq 25 \Omega.m$; and
- (b) 10 V a.c. for soils whose resistivity is $> 25 \Omega.m$.

CIGRE TB 290 provides additional guidance on assessing the risk of a.c. corrosion.

NOTE: Considerable research is being undertaken on developing a better understanding of this phenomenon.

In some locations, the requirement for risk treatment of LFI for control of pipeline corrosion may be more stringent than the requirement for human safety.

3.9 PIPE WALL FUSION

Pipe wall fusion can occur under power line fault conditions if the driving voltage and available current is sufficient. This can occur where a pipe is close to a high voltage power line earth and from lightning strikes to earth close to the pipeline.

It is prudent to assume that a coating defect can occur anywhere on a pipeline and not use the existence of a pipeline coating as defence. There is no simple criterion for defining a limit to the energy discharge needed to fuse the pipe wall.

The parameters that are associated with the risk source are—

- (a) the driving voltage;
- (b) the soil resistivity;
- (c) the presence of any coating defects;
- (d) the size and shape of the defects;
- (e) the wall thickness of the pipe; and
- (f) the proximity of the electrical earth.

In the absence of a satisfactory criterion industry has tended to use a maximum voltage of 10 000 V between the pipeline and earth.

3.10 ELECTRONIC EQUIPMENT

Electronic equipment attached to the pipeline is vulnerable to damage from power line faults (LFI and EPR). Cathodic protection units are particularly vulnerable.

All such equipment should have a high level of surge protection on the field side to cope with surges. The power input side of the equipment may also require significant surge protection.

3.11 CONSTANT POTENTIAL CATHODIC PROTECTION UNITS

Constant potential cathodic protection units are commonly used on well coated pipelines to mitigate stray traction current and telluric effects.

Relatively low levels of induced a.c. under power line operating conditions can cause the closed loop control system to malfunction. This can often be overcome by increasing the time constant of the control system. However, even levels of induced a.c. that are less than the a.c. corrosion criterion can result in time constants that substantially reduce the effectiveness of the units.

Such cathodic protection units should either be located where such levels of induced a.c. are not present, or sufficient controls should be installed to reduce the a.c. induction to a satisfactory level.

3.12 PIPELINE EARTHING TO POWERLINE EARTHS

Earthing the pipeline at specific locations is a method of mitigating the effects of a.c. induction.

If the pipeline earth is tied to the powerline earth, then under fault conditions the voltage on the pipeline is raised to that of the powerline earth.

Earthing systems should be isolated from the power line earth and should be as remote from it as possible. However, there may be some situations, such as a pipeline supplying a power generating station, where this cannot be avoided and a special design should be developed. The earthing of the pipeline close to these facilities should be considered as part of the earthing review by the generation station and incorporated into the station's earthing design.

3.13 PLASTIC PIPELINES CONTAINING CONDUCTIVE LIQUIDS

While unusual, non-metallic pipelines transporting conductive fluids may permit hazardous voltages from a location close to an electrical fault to a remote location where there is no apparent electrical hazard.

For example, plastic and fibreglass water pipelines typically use metal air valves and drain down valves. A cathodically protected valve with a galvanic anode might be installed at one end close to a power line earth. The next valve might be above ground or not earthed. The conductive fluid will create an electrical path between the two valves.

If there is a power line fault, EPR current may then be conducted through the liquid and a person touching the remote valve will be exposed to the potential difference between the remote valve and earth.

If calculations indicate a hazardous condition exists, the design solution should either earth the remote valve(s) or provide an isolation pad or equipotential grid.

Some plastic pipes are manufactured with a built in metal trace wire and some plastic pipes are installed with a separate trace wire in close proximity. In both cases the wire may pick up LFI and so require assessment.

SECTION 4 DESIGN PROCESS (AUSTRALIA ONLY)

4.1 GENERAL

The pipeline electrical hazards risk management plan shall identify locations where there is potential for electrical hazards to the pipeline, pipeline operating and maintenance personnel or to the public. Each assessment shall consider the variation in conditions along the route of the pipeline.

The plan shall document the risk level of the electrical hazard and, if required, shall specify the risk treatment required to reduce the risk level to within acceptable limits. Where it is not possible to eliminate the hazard, the plan shall incorporate additional features that reduce the risk to equipment and personnel to tolerable levels.

Controls shall be documented in the plan. The control measures shall be incorporated in the operating and maintenance procedures for the pipeline.

NOTE: The ENA EG-0 risk based design method for evaluating the contribution of controls to risk sources and assessing the risk level is recommended for systems designed and operated in Australia. This will establish consistency with the methods used to control similar hazards in the power industry.

Because the hazards and control methods change with time, the design shall be monitored and reviewed for each pipeline periodically. The design should be reviewed when circumstances that could change the electrical hazards are identified or at a maximum period of 5 years.

4.2 DESIGN PROCESS

The design process shall involve assessment of the risk against three criteria, based on increasing levels of complexity. These are—

- (a) Level 1—Conservative compliance criteria;
- (b) Level 2—Predetermined voltage limit criteria; and
- (c) Level 3—Risk based (personnel safety) compliance.

After determining the voltage for each scenario, the criteria for each level is based on calculations to determine risk level based on the probabilities of two components.

The basic equation is—

$$\text{Risk} = P_{\text{fibrillation}} \times P_{\text{coincidence}}$$

$P_{\text{fibrillation}}$ is the probability that a voltage incident will occur in the critical part of the cardiac cycle and cause a fatality. It also considers the current path through the body and additional series impedance (e.g. crushed rock, footwear).

$P_{\text{coincidence}}$ relates to the frequency and duration with which a voltage incident is present on the body as well as consideration of the frequency and duration of a person being in a position to contact the voltage.

These values are determined by knowledge of the voltages likely to be present (see Section 3) and the time that a person may be physically contacting the pipe or its fixtures.

Electrically, the human heart beat has many well defined stages. An electrical pulse, even one low in magnitude, occurring in the critical stages of the heart beat cycle can cause serious injury or even be fatal. Conversely other stages of the heart cycle are unaffected by an electrical pulse. AS/NZS 60479.1 shall be used to determine fibrillation probability.

The probability of an individual fatality for those persons exposed to these hazards is categorized in three risk level regions—

- (i) high risk for probability of fibrillation greater than 10^{-4} per year;
- (ii) intermediate risk for probability of fibrillation between 10^{-6} and 10^{-4} per year; and
- (iii) low risk for probability of fibrillation less than 10^{-6} per year.

NOTE: These risk level regions are based on societal levels of acceptable or in the ALARP region to a tolerable risk. For references, see the Bibliography.

The designer shall calculate the voltage on a pipeline from each identified hazard and apply controls to the pipeline to reduce the risk to tolerable levels.

The treatment depends on the risk level as described in Clause 4.5.

The design and the risk assessment process, including all assumptions, shall be documented in sufficient detail for independent or future users (or reviewers) of the design and hazard management plan to make an informed assessment of the integrity of the process and its outcomes, including the identification of hazards and the reasoning behind the assessment of the effectiveness of the control measures applied.

Where the risk assessment assesses a hazard as lying in the intermediate risk region, and the risk is accepted ALARP, the basis for acceptance shall be justified in accordance with the definition of this term.

The risk assessment shall be undertaken in accordance with this Section.

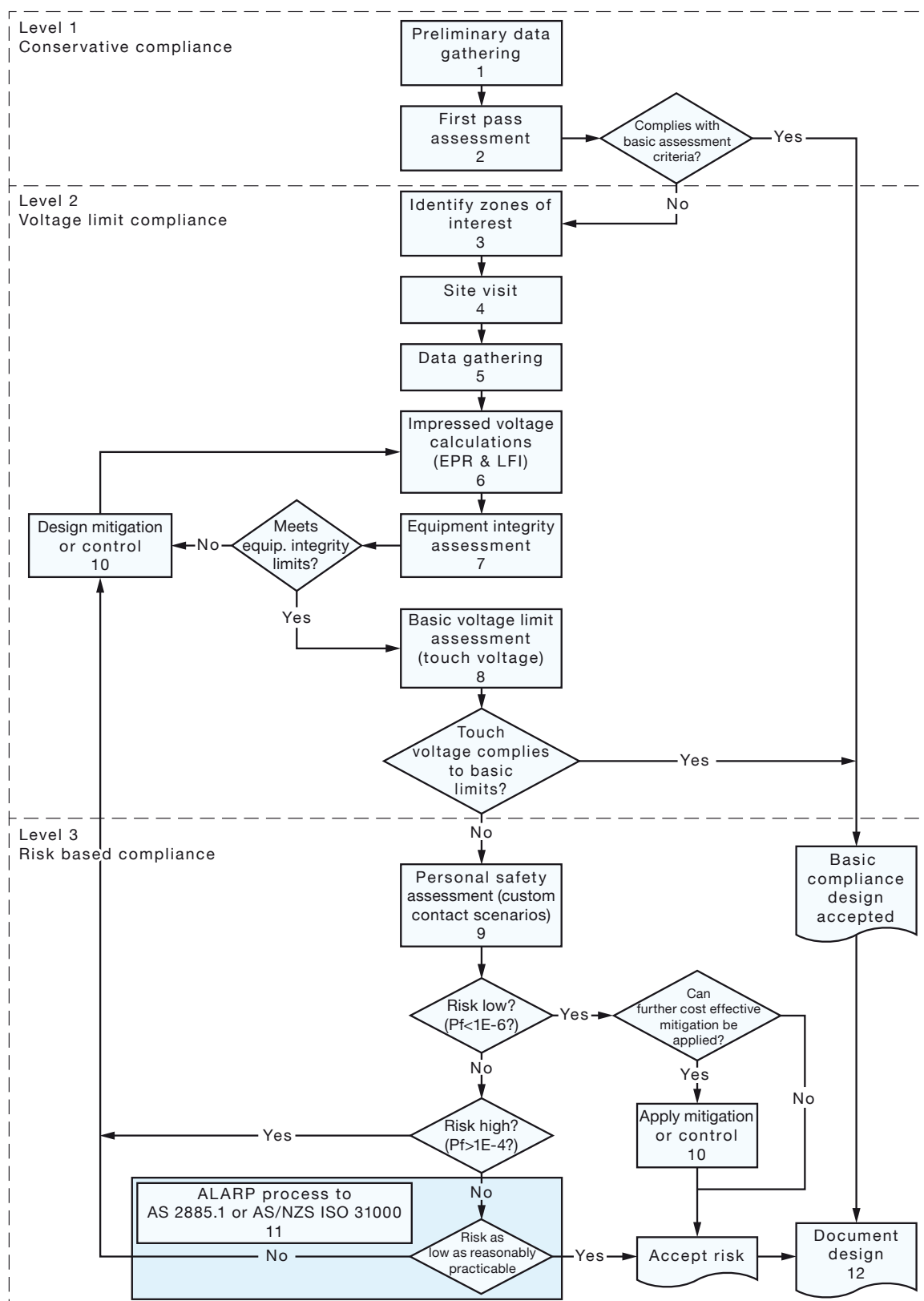


FIGURE 4.1 ELECTRICAL HAZARD DESIGN PROCESS

TABLE 4.1
DESIGN PROCESS

	Step	Process description	Process
Level 1	1	Preliminary data gathering	Some basic data is required to provide a conservative determination of the acceptability of the a.c. exposure, without a field trip or obtaining detailed powerline information. This requires knowledge of the pipeline route, the powerline route and the type of powerline. Refer Clause 4.3.1.
	2	First pass assessment	The first pass assessment of acceptability of the a.c. exposure is based on graphs of exposure lengths against pipeline separation for LFI, and separation distances for EPR. The criteria provided in the first pass assessment are based on conservative values for fault current, soil resistivity and pipeline coating condition. Refer Clause 4.3.2.
Level 2	3	Identifying zones of interest	If the exposure lengths exceed the conservative criteria in the first pass assessment, the areas of non-compliance are identified as zones of interest. Refer Clause 4.4.1.
	4	Site visit	A site visit is required to obtain accurate pipeline-powerline separations, identify the power lines, measure soil resistivities and other data. Refer Clause 4.4.2.
	5	Data gathering	In order to determine accurate EPR and LFI voltages detailed information is required on the pipeline, the powerline and their relative geometries. Refer Clause 4.4.3.
	6	Impressed voltage calculations	The LFI under powerline load conditions can be calculated, and the LFI and EPR under powerline fault conditions calculated. Refer Clause 4.4.4.
	7	Equipment integrity assessment	To determine whether the pipeline and/or equipment can withstand the impressed voltages. Refer Clause 4.4.5.
	8	Basic voltage limit assessment	The calculated prospective touch voltages are compared with a tabulation of typical predefined contact scenarios for various pipeline types, and activities associated with those pipeline types. The tabulation presents the maximum voltage for each contact scenario to comply with the risk of fibrillation of less than 10^{-6} . The predefined typical scenarios shall be assessed against expected actual scenarios (refer Clause 4.4.6) and if not applicable, go directly to step 9.
Level 3	9	Personnel safety assessment	Determination of the risk level is based upon a activity specific contact scenario. Refer Clause 4.5.
	10	Design or application of risk treatment or control	The application and design of various risk treatment strategies or controls to reduce the hazard and risk level. Refer Section 4.
	11	ALARP process	The application of the 'As low as reasonably practicable' principle described in Clause 4.5.5.
	12	Documentation	Documentation shall include the physical installation description (e.g. drawings) as well as electrical assumptions, design decisions, commissioning data, an monitoring and maintenance requirements. Refer Clause 7.4.

4.3 LEVEL 1 (CONSERVATIVE) COMPLIANCE

4.3.1 Preliminary data gathering

Preliminary data on pipeline and electrical sources shall be obtained to identify zones of interest that may require further assessment.

The minimum data that shall be obtained is as follows:

- (a) Pipeline route drawing with facilities (e.g. CP test points, valves).

- (b) Powerline routes and earthed facilities (e.g. earthed poles/towers, substations, pad mount kiosks/transformers, switchyards, electric traction systems).
- (c) Power line type (i.e. transmission 66 kV and above or distribution less than 66 kV).
- (d) Power line fault current (optional).

4.3.2 First pass assessment

4.3.2.1 General

The first pass assessment is undertaken to determine whether the exposure is likely to cause an electrical hazard of sufficient magnitude to require more detailed analysis. If the assessment determines that the exposure satisfies the requirements of LFI (Table 4.2 or 4.4) or EPR (Table 4.3 or 4.5), the potential hazard is low, and the risk level is tolerable. Locations that do not satisfy the conservative assessment criteria are zones of interest, and require more detailed analysis (Clause 4.4).

4.3.2.2 Distribution power lines—Low frequency induction

For the potential hazard to be accepted as low risk on the basis of a conservative assessment, the pipeline exposure length (average separation for the parallel section) under LFI conditions shall be less than the values given in Table 4.2.

TABLE 4.2
CONSERVATIVE EXPOSURE LENGTH FOR PIPELINES SUBJECT TO LFI
FROM DISTRIBUTION POWER LINES

Power line to pipeline separation (m)	Exposure length (m)		
	100 Ω .m	500 Ω .m	1000 Ω .m
5	180	160	150
10	210	180	170
20	240	200	190
50	310	250	230
100	400	300	280
200	550	390	340
500	950	600	500

NOTES:

- 1 Separation is the shortest distance between the pipeline and the closest phase conductor.
- 2 Assumptions used in calculating the exposure length—
 - (a) no OHEW or shielding applied;
 - (b) source substation grid resistance = 0.35 Ω ;
 - (c) pole earth resistance = 10 Ω ;
 - (d) fault current (1 kA) flows through line conductor and faulted pole earth resistance; and
 - (e) soil resistivity = deep layer values.
- 3 These assessment limits are based upon a conservative allowable prospective touch voltage of 58 V for distribution power lines (refer to Table K2).

4.3.2.3 Distribution power lines—Earth potential rise

For the potential hazard to be accepted as low risk on the basis of a first pass assessment the separation between a distribution power line conductive structure or substation and a pipeline subject to EPR shall be greater than the values in Table 4.3 for varying power line fault currents and surface soil resistivity.

TABLE 4.3
CONSERVATIVE SEPARATION DISTANCE FOR PIPELINES SUBJECT TO EPR
FROM DISTRIBUTION POWERLINES

Fault current or actual current (A)	Separation required (m) for two resistivity values	
	100 $\Omega\cdot\text{m}$	500 $\Omega\cdot\text{m}$
150	40	190
300	80	390
500	130	660
750	200	1000
1000	270	1300

NOTES:

- 1 Separation required is from the pole or substation earthing system to the pipeline appurtenances, access points or earth points.
- 2 If the fault current is unknown, use 1 kA in this first pass assessment. Use an earth resistivity of 500 $\Omega\cdot\text{m}$ for dry sand or rock and 100 $\Omega\cdot\text{m}$ for all other cases.
- 3 Assumptions used in calculating the separation—
 - (a) no overhead earth wire;
 - (b) pole resistance = 10 Ω ; and
 - (c) fault current flows through line conductor and faulted pole earth resistance.
- 4 These assessment limits are based upon a conservative allowable prospective touch voltage of 60 V for distribution power lines (refer to Table K2).

4.3.2.4 Transmission power lines—Low frequency induction

For the potential hazard to be accepted as low risk on the basis of a first pass assessment the pipeline exposure length (parallelism) under LFI conditions shall be less than the values given in Table 4.4.

TABLE 4.4
CONSERVATIVE EXPOSURE LENGTH FOR PIPELINES SUBJECT TO LFI
FROM TRANSMISSION POWER LINES

Power line to pipeline separation (m)	Exposure length (m)		
	100 Ω .m	500 Ω .m	1000 Ω .m
5	95	82	78
10	110	93	87
20	127	106	100
50	165	131	120
100	210	160	145
200	290	202	178
500	500	310	260

NOTES TO TABLE 4.4:

- 1 Separation shall be the direct distance between pipeline and closest phase conductor.
- 2 Assumptions used in calculating the exposure length—
 - (a) shielding factor of 0.8;
 - (b) fault current is fixed at 8 kA;
 - (c) source substation grid resistance = 0.1 Ω ;
 - (d) tower resistance = 5 Ω ;
 - (e) fault current flows down several tower resistances; and
 - (f) soil resistivity = deep layer values.
- 3 These assessment limits are based upon a conservative allowable prospective touch voltage of 220 V for transmission power lines (refer to Table K2).

4.3.2.5 Transmission power lines—Earth potential rise

For the potential hazard to be accepted as low risk on the basis of a first pass assessment the separation between a transmission power line structure and a pipeline shall be greater than the values in Table 4.5 for varying power line fault currents and surface soil resistivity.

TABLE 4.5
CONSERVATIVE SEPARATION DISTANCE FOR PIPELINES SUBJECT TO EPR
FROM TRANSMISSION POWERLINES

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

NOTES:

- 1 Separation required is from the pole or substation earthing system to the pipeline appurtenance, access point or earth point.
- 2 If the transmission line uses an OHEW, use values up to 3000 A (this assumes a current split of 30% of 10 kA). For lines without an OHEW, use values up to 10000 A for current going down the structure. Use an earth resistivity of 500 Ω .m for dry sand or rock, 100 Ω .m for all other cases.
- 3 Assumptions used in calculating the separation—
 - (a) source substation grid resistance = 0.1 Ω ; and
 - (b) tower resistance = 5 Ω .
- 4 These assessment limits are based upon a conservative allowable prospective touch voltage of 220 V for transmission power lines (refer to Paragraph K2).

4.4 LEVEL 2 VOLTAGE LIMIT COMPLIANCE

4.4.1 Identifying zones of interest

Zones of interest are locations that are not accepted as low risk by the first pass assessment. These locations shall be analysed in detail.

4.4.2 Site visit

A site inspection shall be undertaken by a competent person to establish accurate data on—

- (a) the powerline (or other hazard);
- (b) the spatial relationship between the hazard and the pipeline;
- (c) the exposure length;
- (d) soil resistivity; and
- (e) general characteristics of the installation.

A project geographic information system (GIS) may be used in this identification. However, spatial data from the GIS should not be used unless the quality and accuracy of the data relative to the pipeline centreline and other spatial data is verified.

As a minimum, data gathered during the site visit should include the following:

- (i) Inspection details and/or mapping of the pipeline route.
- (ii) Identification of each power pole or tower by its unique ID number.
- (iii) The power company may be able to supply numbers with GIS.
- (iv) Measurement of the exact separations between pipeline and powerline poles/towers.
- (v) Measurement of the length of parallelisms.
- (vi) At zones of interest, measurement of soil resistivity with Wenner pin spacings to a minimum of 32 m to enable calculation of EPR and LFI, and earthing design. (Refer to Appendix L.)

- (f) Measurement of the resistance to earth of galvanic anodes, pipeline facility earths and any other pipeline earthing systems (where they exist).

4.4.3 Data gathering

A substantial amount of data regarding the high voltage powerlines and the pipelines is required in order for the analysis to achieve the accuracy needed for safety assessment in accordance with this Standard.

The following data, listed in four basic categories, shall be gathered:

(a) *System geometry*

Prepare a drawing of the pipeline and relevant powerlines at such a scale that the distance between them can be determined to an adequate resolution. As a guide, the resolution should be within 10% of the measurement.

The drawing shall, at least, indicate the location of the following:

- (i) Powerline poles/towers.
- (ii) Cable joint/termination pits.
- (iii) Substations and switchyards.
- (iv) Pipeline routes.
- (v) CP test points, valves and isolating joints.
- (vi) Passive conductive structures, e.g. railways, other pipelines and powerlines within zone of interest.
- (vii) Earthing system locations.

(b) *Pipeline data*

Obtain the following pipeline data:

(i) *Pipeline construction*

- (A) Material.
- (B) Outside diameter.
- (C) Pipeline wall thickness.
- (D) Burial depth to pipe centreline
- (E) Length of pipeline between isolating joints.
- (F) Working pressure.
- (G) Distance pipeline parallels high voltage power line.

(ii) *Jointing mechanism*

- (A) Welded.
- (B) Rubber ringed joint (cross bonding cables).
- (C) Type of insulating joints, e.g. flange insulating kit (FIK), monolithic insulating joints (MIJ).
- (D) Other.

(iii) *Coating system*

- (A) Pipeline.
- (B) Coating type and thickness
- (C) Effective insulation strength (kV)

- (D) Effective resistance to earth (Ω)
- (E) Field joints.
- (F) Ancillary fittings.
- (G) Resistivity.
- (H) Thickness.
- (iv) *Off takes* (quantity and locations)
 - (A) Third party.
 - (B) Scours.
 - (C) Air valves.
 - (D) Monitoring/flow equipment.
 - (E) Pits.
- (v) *Other underground utilities* (in vicinity of easement)
- (vi) *Cathodic protection*
 - (A) Details of proposed or existing cathodic protection.
 - (B) Surge protection type e.g. polarization cells, spark gaps, surge diverters.
 - (C) Earthing resistance of galvanic anodes, a.c. earthing.
 - (D) Earthing beds, facility earths (type, location, circuit resistance).
- (c) *High voltage power line operational parameters*

The operational parameters of the high voltage power line or cable which may need to be assessed include the following:

 - (i) Phase to phase voltage.
 - (ii) Maximum load current.
 - (iii) Configuration of conductors and supports.
 - (iv) Conductor details for phase and earth wires including stranding number, diameter, material and d.c. resistance at 20°C.
 - (v) Transposition scheme—location of cross points and estimation of balance.
 - (vi) Primary fault clearance time (excluding auto-reclosure since delay times applied between recloses are sufficient for reflex action to remove contact).
 - (vii) Fault current profile—from both ends if part of a grid system (see Figure 4.2).
 - (viii) Phase to earth fault frequency of powerline (faults/100km/yr).
 - (ix) Overhead earth wires—number of, shielding factor, extent of (e.g. for all or part of route).
 - (x) Average height of lowest conductor from ground.
 - (xi) Magnetic field under phase conductors at ground level (due to load current).
 - (xii) Average tower footing resistance, and radial extent of tower earthing system (e.g. counterpoise conductors).
 - (xiii) Soil resistivity—relatively shallow for EPR calculations near towers (see Paragraph G4.3.3), deeper for LFI calculations.
 - (xiv) Shielding factor of OHEW.
 - (xv) EPR and voltage contours in zones of interest.

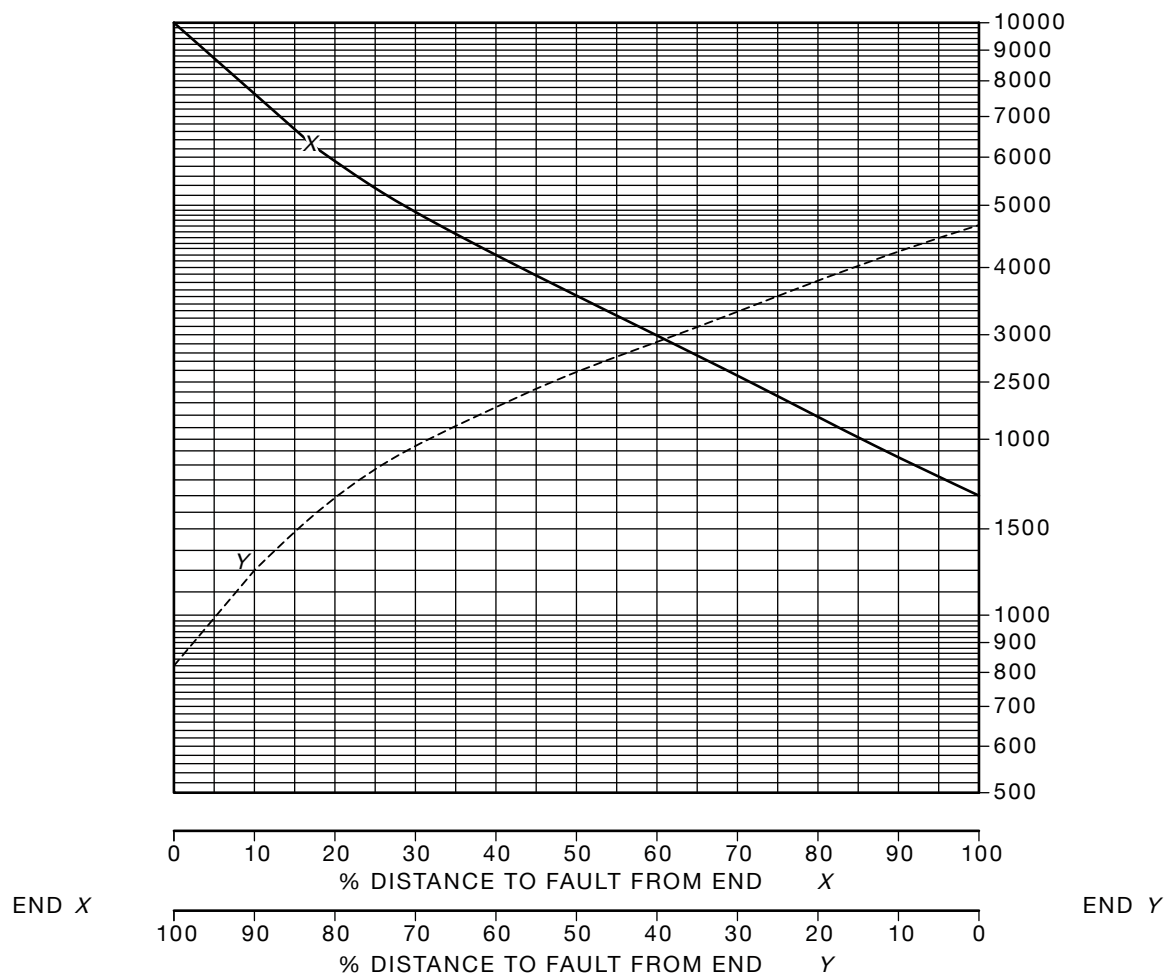
(d) *High voltage power line 'life cycle'*

Many of the parameters listed in Item (b) may be affected by changes to the high voltage power system that may happen sometime in the future. Therefore, when assessing parameters, long-term plans should be obtained where available.

The following items shall be considered:

- (i) Changes of voltage.
- (ii) Changes of load current.
- (iii) Changes of fault current.
- (iv) Extensions to route.

Notwithstanding the above, it may in some cases be more economical to mitigate for present hazards and address future hazards at the appropriate time.



NOTE: The Y axis is the circuit single phase earth fault current in amps. Where there is more than one circuit on the same easement, this profile represents the net $3I_0$ of the faulted and healthy circuits.

FIGURE 4.2 AN EXAMPLE OF A FAULT CURRENT PROFILE

The prospective earth fault current in the vicinity of the pipeline area of interest shall be provided. This prospective earth fault level is the available system fault capacity at certain points along the powerline. When an earth fault occurs, current will flow through a phase conductor and then into the ground via any interconnected earth electrode.

Earth electrodes are specifically installed to provide a low resistance earth return path through the ground and will vary in resistance value depending on the type of high voltage installation. The earth resistance of the high voltage installation that is either a measured value or minimum design value shall also be provided.

The earth electrode resistance shall be used to calculate the true earth fault current entering the ground and not the prospective earth fault level which is a theoretical maximum based on zero ohm earth impedance. Use of the prospective earth fault value results in an overestimate of the true earth fault current because it ignores the impedance of the earth electrode.

4.4.4 Impressed voltage calculations

The a.c. interference from EPR and LFI shall be determined separately and then the total effect summed vectorially.

If the pipeline is parallel to the power line then the LFI may be determined by calculation. (See Appendices B and C.)

The method may also be used where the pipeline and power line are essentially parallel, but the geometry does vary along the route, by using a mean separation between the structures for the determination.

Where the geometry between the pipeline and power line is complex with areas of parallelism and intersection, computer modelling may be required to determine the LFI. This may also be necessary if there are insulating joints in the pipeline close to the area of interference.

Commercially available software may be used to assist in analysing complex LFI and EPR systems. While these are useful, experience has shown that most software contains simplifying assumptions. The designer should take care to understand the assumptions, the limits of any software functions, and the extent of validation underlying the software packages.

The designer should also undertake sufficient analysis of calculation variables (e.g. soil resistivity, seasonal variation effect on electrodes buried in the surface layers) to ensure that the decision is adequately robust.

The designer should apply conservative allowances to recognize the limits of software, or the sensitivity to calculation variables.

The LFI should be determined under both power line load and fault conditions. The load condition is required for the determination of personnel safety risk and a.c. corrosion. The fault condition is required for evaluation of faults occurring at towers along the route for the determination of personnel safety risk and damage to ancillary equipment. The fault current at each tower shall be used, to determine the greatest exposure.

EPR should be calculated for all earthed structures (substations, towers or poles, and cable joint bays) that are close to the pipeline.

NOTE: The method for calculating EPR near a high voltage installation is given in Appendix G.

4.4.5 Equipment integrity assessment

The calculated voltage (under load and fault conditions) on a pipeline shall be assessed to determine whether it is capable of affecting the integrity of the equipment, and of the pipeline. If the assessment determines that there is a risk to the pipeline integrity, controls shall be applied to reduce the voltage to a non-hazardous value, or the pipeline and its equipment shall be changed, or both.

NOTES:

- 1 Under power line fault conditions there are three hazards, as follows:
 - (a) If there is electrical equipment attached to the pipeline, such as cathodic protection units or telemetry, they may be affected by voltages as low as 1000 V unless appropriate surge protection is installed. (Surge protection installed to mitigate against lightning may not be appropriately rated for fault currents.)
 - (b) Insulation flange kits are typically rated at 1000 V and monolithic insulation joints at 5000 V and may be affected unless appropriate surge protection is installed. (Surge protection installed to mitigate against lightning may not be appropriate for the control of appropriately rated fault currents).
 - (c) Pipeline coatings may be damaged by voltages of the order of 5000 V but the damage is likely to be small and local. Pipeline integrity should be secure at voltages up to 10000 V.
- 2 The likelihood of induced a.c. corrosion of the pipe metal under powerline load conditions shall be assessed in accordance with Clause 3.8.

4.4.6 Voltage limit compliance

The risk profile associated with earthing systems varies greatly for different locations and circumstances. The hazard contact scenarios applicable to the particular site and power system configuration that could be presented during the period of the project and life of the installation/asset shall be identified during the first phase of earthing system design or redesign.

Hazard contact scenarios have been developed that represent the frequency and duration of contact by public and pipeline personnel with the metallic pipeline, during typical construction, and operating and maintenance activities undertaken throughout the pipeline operating life.

The calculated touch or step voltage shall be assessed for compliance with basic personnel safety criteria in Tables 4.6 or 4.7.

NOTE: The basic voltage criteria are developed for the contact scenarios detailed in Appendix K.

The contact scenarios represent typical circumstances, frequencies and durations for personnel who contact a pipeline, and are considered reasonable estimates for the initial design. The pipeline owner or licensee shall review and expand the scenarios as appropriate to reflect realistic contact scenarios for each asset, and revise them to reflect realistic contact frequencies and duration for that asset.

Once the prospective touch voltages are calculated, the voltages and the contact scenario should be tested against Table 4.6 or Table 4.7 for compliance.

NOTE: If the predefined contact scenarios do not apply to the actual scenario go directly to Clause 4.5.

The Tables 4.6 and 4.7 present the maximum voltage for which the individual probability of fibrillation (P_f) is below 10^{-6} .

Calculated voltages lower than these values produce a negligible likelihood of fibrillation.

If the calculated prospective voltage is greater than those in Tables 4.6 and 4.7, Level 3 (Personal safety) compliance is required as described in Clause 4.5.

NOTES:

- 1 Where EPR is the only hazard the resultant prospective touch voltage is equal to the voltage between where the person is standing and the pipeline, assuming the pipeline is at remote earth potential.
- 2 Where both LFI and EPR hazards have been identified the resultant prospective touch voltage is the vector difference between the EPR where the person is standing and the LFI voltage on the pipeline.
- 3 Where only an LFI hazard has been identified the prospective touch voltage is the pipeline LFI voltage.
- 4 The voltage limits calculated are based upon power line fault conditions and contact scenarios presented in Appendix K. The voltage limit for load conditions is either governed by the requirement to limit a.c. corrosion or for personnel safety.

TABLE 4.6
DISTRIBUTION POWER LINE VOLTAGE LIMITS

Affected Person	Pipeline contact scenario	Current path	Voltage for $P_f < 10^{-6}$ (volt)
Public	Regulator metallic pit lids	Step	≤ 1700
	Scour or air valve	Touch	≤ 120
	Air valve in playgrounds, sporting fields etc	Touch	≤ 50
	Houses (as per ENA EG-0 TDMEN)	Touch	≤ 80
Pipeline operators	Gas valve operation	Touch	≤ 70
	Water valve operation	Touch	≤ 58
	CP test point inspections	Touch	≤ 75
Construction worker	New gas pipeline	Touch	≤ 110
	Tee-off from long exposed pipe	Touch	≤ 110
Maintenance worker	Leak repair on water pipe	Touch	≤ 95
	Leak repair on gas pipe	Touch	See Note 1

TABLE 4.7
TRANSMISSION POWER LINE VOLTAGE LIMITS

Affected Person	Pipeline contact scenario	Current path	Voltage for $P_f < 10^{-6}$ (volt)
Public	Valves or CP points	Touch	See Note 1
Pipeline operators	Gas valve operation	Touch	≤ 500
	Water valve operation	Touch	≤ 20
	CP test point inspections for transmission pipeline	Touch	≤ 540
Construction worker	New gas pipeline	Touch	≤ 650
	Tee-off from long exposed pipe	Touch	≤ 600
Maintenance worker	Leak repair on water pipe	Touch	≤ 510
	Leak repair on gas pipe	Touch	See Note 1

NOTES:

- 1 These cases are extremely low risk situations requiring no voltage limit.
- 2 Details of the example contact scenarios are given in Appendix K.

4.5 LEVEL 3 RISK BASED (PERSONAL SAFETY) COMPLIANCE

4.5.1 General

The voltage criteria are levels that represent low risk. If the voltage criteria are not satisfied, the risk level is either intermediate or high, or it is possible that the specific scenarios do not match the assumptions made in Appendix K.

Additional controls (i.e. physical protection) shall be applied to reduce the voltage and the voltage recalculated, and the assessment repeated.

If further voltage reduction is not possible, additional risk treatment measures (physical or procedural methods) shall be applied and the assessment repeated. The iterative process shall be repeated until the risk level is assessed as low.

If after all reasonable risk treatment measures have been applied the risk level is still intermediate, the design may be accepted if the risk level is assessed as being reduced to ALARP. The basis for this decision shall be documented.

To ensure the integrity of the design process, hazards assessed as being low risk shall be reassessed to ensure all reasonable control measures have been applied.

4.5.2 Applicable voltage scenarios

The touch voltage becomes the effective (loaded) touch voltage when the conductive parts are being touched simultaneously, and is loaded by the body impedance along the current path.

NOTE: When comparing calculated or measured touch voltages with touch voltage limits, the touch voltage is taken as the potential difference between the conductive part and any point on the surface of the earth within a horizontal distance of 1 m from the vertical projection of the point of contact with the conductive part.

4.5.3 Methodology

The probabilistic (safety criteria) method enables a designer to develop (or select) touch voltage criteria that reflect the following requirements:

- (a) Multiple independent resistances (controls), e.g. footwear, soil, crushed rock or asphalt.
- (b) Frequency and duration of both earth faults and contact by people.
- (c) Acceptable individual risk level and societal risk targets.

The probabilistic method enables the designer to identify hazard scenarios where more traditional approaches are non-conservative and more stringent criteria may be justified on account of the risk profile to which the public or utility staff may be exposed.

The probabilistic method applied in this Standard is a form of quantified risk analysis. It recognizes that a fatality due to an earth fault can only occur if both of the following situations exist:

- (i) A person is present when a fault occurs.
- (ii) Touch (or step) voltage generated is sufficient to allow a large enough current to pass through the body for sufficient time to cause fibrillation of the heart muscle.

For a given fault/contact scenario the designer shall determine a voltage/time curve that maintains the risk of fatality within acceptable limits. The process is described in ENA EG-0.

The probabilistic method calculations may be performed manually; however, the ARGON software program available with ENA EG-0, is approved as a tool for assessing and documenting the risk assessment process. Other software or risk assessment methods that satisfy the intent of this Standard may be approved.

The following Clauses describe the steps involved in the process of quantifying the risk levels.

4.5.4 Coincidence probability calculations

The first stage in the derivation process is to determine the likelihood of a person being present at the time of a fault occurrence (i.e. P_{coinc}). The parameters to be assessed are described in Table 4.8.

TABLE 4.8
COINCIDENCE PROBABILITY INPUT PARAMETER SUMMARY

Input parameter	Description or range
Earth fault frequency	Faults/year
Earth fault duration	Seconds
Contact frequency	Contacts/year
Contact duration	Seconds

If the coincidence probability is less than the allowable societal risk levels (i.e. $\leq 10^{-6}$) the hazard is of an acceptable level independent of the fibrillation probability.

4.5.4.1 Fibrillation probability calculations

Fibrillation probability depends upon a number of parameters in addition to the position and susceptibility of the person and the applied voltage. These include the following:

(a) *Surface soil resistivity*

Surface soil resistivity has a significant effect on the current that can pass through a body. The effect of soil resistivity is linear with the effect on the body and results can be interpolated linearly between two resistivities to provide the effect at the required resistivity when undertaking Argon based analysis.

(b) *Footwear*

Appropriate footwear can significantly reduce the current that can pass through a body. Under dry conditions any enclosed leather or non conductive rubber or plastic footwear in good condition is as effective as electrical safety boots in reducing the risk. Without such footwear the risk is equivalent to bare feet. Under wet conditions appropriate gum boots in good condition are as effective as electrical safety boots in dry conditions. Without such gum boots in wet conditions the risk is as with bare feet.

NOTES:

- 1 Appropriate gum boots are gum boots which pass the following test to ensure that the material from which they are made is insulating: fill the boot to approximately 90% of its height with salt water and place it in a container of salt water that reaches the same water level. The resistance between electrodes inserted in the water inside the boot and outside of the boot should be determined with a high voltage resistance tester. The resistance should not be less than 1 megohm.
- 2 Gumboots should be maintained in good condition and replaced if any splits or cracks appear.

(c) *Surface layers*

The two main surface layer materials in common usage are crushed rock and asphalt. These materials exhibit a wide range of electrical properties both initially and over time and any design requiring their use for safety reasons should take care to ensure the installation matches the required specification. Options include:

(i) *Crushed rock*

This is only considered effective when installed within a secured area. It commonly serves multiple roles, including series resistance, vehicle driveway and walkway, and weed control layer. Therefore, its specification shall consider electrical properties and trafficability.

A typical specification should include figures such as the following:

- (A) Installed depth: At least 100 mm.
- (B) Gravel size: 30 – 50 mm.
- (C) Electrical properties: $\geq 3000 \Omega.m$ when wet.

NOTES:

- 1 The specification should not be left open as quarries may provide material that has too large a range of gravel size (i.e. too many fines (poor electrical quality), and too large size (poor trafficability), and poor electrical resistivity performance.
- 2 20 mm gravel may be more serviceable where the installed depth is 100 mm.
- 3 Prior to accepting delivery of the full consignment of material some utilities carry out a brief testing process [see ENA EG-0].

(ii) *Asphalt*

Asphalt may also be used to limit body current flow and allow trafficability of vehicles and people.

Unfortunately asphalt exhibits highly variable electrical properties as shown in HV testing research [see ENA EG-0]. Therefore care shall be taken in the specification of asphalt for body current limiting purposes. The following key aspects should be considered:

- (A) Preparation: Use of compacted road base (and possibly plastic underlay for weed control).
- (B) Material: Well compacted hot mix at least 50 mm thickness compacted (as the electrical properties of cold mix are compromised in wet conditions).
- (C) Electrical properties: As it is difficult to type test a batch of hot asphalt, conservative values of resistance and voltage withstand are often used. In the fibrillation tables within the Argon software the following values are assumed:
 - (1) Hot mix asphalt Resistivity – $10,000 \Omega.m$.
 - (2) Hot mix asphalt Voltage withstand – 3 kV.

(iii) *Concrete slabs*

Concrete slabs which are covered so that they are not subject to water (eg rain or shower) have an effective resistivity in the order of $3,000 \Omega.m$.

NOTE: Concrete slabs which are exposed to the weather do not provide an effective resistance barrier but do provide a level, usually dry surface. Touch voltage control may be achieved by bonding to the concrete reinforcement to create an equipotential grid.

If the coincidence value calculated does not meet the 'negligible risk' target then the fibrillation probability may be calculated and used to reduce the expected fatality probability. A series of voltage time curves incorporated into the Argon software have been derived that have constant fibrillation probability independent of fault duration based upon AS/NZS 60479. The parameters to be assessed are described in Table 4.9.

TABLE 4.9
FIBRILLATION PROBABILITY INPUT PARAMETER SUMMARY

Input parameter	Description or range
Current path	Touch, step and hand to hand
Footwear type	None, standard, safety shoes
Surface soil resistivity	5, 50, 100, 500, 1000, 2000, 5000 Ω .m
Surface layer type	None, crushed rock, asphalt, concrete slab

4.5.4.2 Risk evaluation

The expected probability of fatality associated with the specified fault/contact and applied voltage scenario selected can be calculated using the Argon software. A similar process shall be applied for any contact configuration (i.e. touch, transfer, step or hand to hand) and the lower (i.e. more stringent) voltage curve used for the design of the earthing system.

There are three possible outcomes as follows:

(a) *Probability of fatality* $<10^{-6}$

The design is considered compliant if the probability of fatality $<10^{-6}$.

(b) *Probability of fatality* $\geq 10^{-4}$

Should the outcome lie in the intolerable region (i.e. $>10^{-4}$), the risk shall be treated to reduce the risk level to no higher than ALARP.

(c) $10^{-6} < \text{Probability of fatality} < 10^{-4}$

If the risk is assessed to lie in the ALARP region, then the process in Clause 4.5.5 shall be followed. The ALARP decision making process is applied when cost and/or practicability may make any risk treatment measures difficult to justify.

4.5.5 ALARP process

If the combined EPR and LFI voltages exceed the criteria in Clause 4.5, and risk treatment does not reduce the risk to $<10^{-6}$, an ALARP process shall be undertaken. The ALARP process shall be undertaken in accordance with the procedures in AS 2885.1 for gas or liquid petroleum pipelines or developed in accordance with the principles in AS/NZS ISO 31000 for other pipelines.

4.5.6 Documentation

The design, the risk treatment, the risk assessment and if used the ALARP analysis shall be documented in accordance with the requirements of Clause 4.2.1.

The physical protection control methods shall be incorporated in the design.

The procedural protection control methods shall be documented and incorporated into the pipeline management system (pipelines designed and operated to the AS 2885 series) or for other pipelines, the pipeline safety and operating plan. Where necessary, standard operating procedures and work methods shall be written or revised to incorporate the procedural methods required to reduce risk level to the acceptance criteria.

SECTION 5 DESIGN PROCESS (NEW ZEALAND ONLY)

5.1 GENERAL

The pipeline Electrical Hazards Management Plan shall identify locations where there is a potential for electrical hazards to the pipeline, pipeline operating and maintenance personnel or to the public. The plan shall document the magnitude of the electrical hazard, and if required, shall specify the risk treatment to control the risk to within acceptable limits. Where it is not possible to eliminate the hazard, the plan shall incorporate additional features that reduce the risk to equipment and personnel to acceptable levels.

Physical and procedural controls shall be documented in the plan. The control measures shall be incorporated in the operating and maintenance procedures for the pipeline.

Each pipeline design shall identify locations where there is a potential for electrical hazards to the pipeline itself, to pipeline operating and maintenance personnel or to the public. The design shall determine the magnitude of the electrical hazard, and where required, shall incorporate devices that control the magnitude of the hazard to safe limits.

Where it is not practicable to reduce the hazard to levels that are inherently safe, the design shall incorporate additional features that will reduce the risk to equipment and personnel to acceptable levels.

The design, including controls by procedures and through the use of personal protective equipment shall be documented and the procedural requirements shall be incorporated in the operating and maintenance procedures for the pipeline.

Where it is not possible to reduce the hazard to levels that are inherently safe, a risk management based design method shall be used to quantify the contribution made by each identified control in reducing the risk from the identified hazard to an acceptable level.

NOTE: The EEA *Guide to Power System Earthing Practice* is recommended for systems designed and operated in New Zealand.

Because the hazards and required control methods may change with time the electrical hazard management plan for each pipeline shall be monitored and reviewed periodically. The design should be reviewed when circumstances that could change the electrical hazards are identified, or at a maximum period of 5 years.

5.2 DESIGN PROCESS

The design process shall involve assessment of the risk against three criteria, based on increasing levels of complexity. These are—

- (a) Level 1—Conservative compliance criteria; and
- (b) Level 2/3—Risk based compliance.

After determining the voltage for each scenario, the criteria for each level is based on calculations to determine risk levels based on the probabilities of two components.

$$\text{Risk} = P_{\text{fibrillation}} \times P_{\text{coincidence}}$$

$P_{\text{fibrillation}}$ is the probability that a voltage incident will occur in the critical part of the cycle and cause a fatality.

NOTE: In New Zealand $P_{\text{fibrillation}}$ is considered to be 1 for voltages exceeding the respective voltage limits and 0 for voltages less than the respective voltage limits.

$P_{\text{coincidence}}$ relates to the magnitude duration that a voltage incident is present on the body as well as consideration of the current path through the body.

These values are determined by knowledge of the voltages likely to be present (see Section 3) and the time that a person may be physically contacting the pipe or its fixtures.

Electrically, the human heart beat has many well defined stages. An electrical pulse, even low in magnitude, occurring in the critical stages of the heart beat cycle can cause serious injury or even be fatal. Conversely other stages of the heart cycle are unaffected by an electrical pulse. AS/NZS 60479.1 is used to determine fibrillation probability.

The probability of an individual fatality for those persons exposed to these hazards is categorized in three risk level regions—

- (i) high risk level for probability of fibrillation greater than 10^{-4} per year;
- (ii) intermediate risk level for probability of fibrillation between 10^{-6} and 10^{-4} per year; and
- (iii) low risk level for probability of fibrillation less than 10^{-6} per year.

NOTE: These regions are based on societal levels of acceptable or in the ALARP region, tolerable risk. For references, see the Bibliography.

The design task is to calculate the voltage on a pipeline from each identified hazard and apply control to the pipeline to reduce the risk to acceptable levels.

The treatment (either mitigation or control) depends on the risk levels.

A fatality risk level of 10^{-4} per year, or greater, in the high risk region is intolerable and shall be mitigated independent of cost.

A fatality risk level of 10^{-6} per year, or less, in the low risk region is generally considered negligible. However, if a substantial reduction in risk can be achieved with relatively low cost controls, then they should be implemented.

For the Intermediate risk region, between 10^{-6} and 10^{-4} per year, the risk may be tolerable provided that it can be demonstrated that the risk has been reduced to As Low As Reasonably Practicable (ALARP).

The design process is presented in Figure 5.1, and detailed in Table 5.1 and the remainder of this Section.

The design and the risk assessment process, including all assumptions, shall be documented in sufficient detail for independent or future users (or reviewers) of the design and electrical hazard risk management plan to make an informed assessment of the integrity of the process and its outcomes, including the identification of hazards and the reasoning behind the assessment of the effectiveness of the control measures applied.

Where the risk assessment assesses a hazard as lying in the intermediate risk region, and the risk is accepted as ALARP, the basis for acceptance shall be justified in accordance with the definition of this term.

The risk shall be assessed in accordance with this Section.

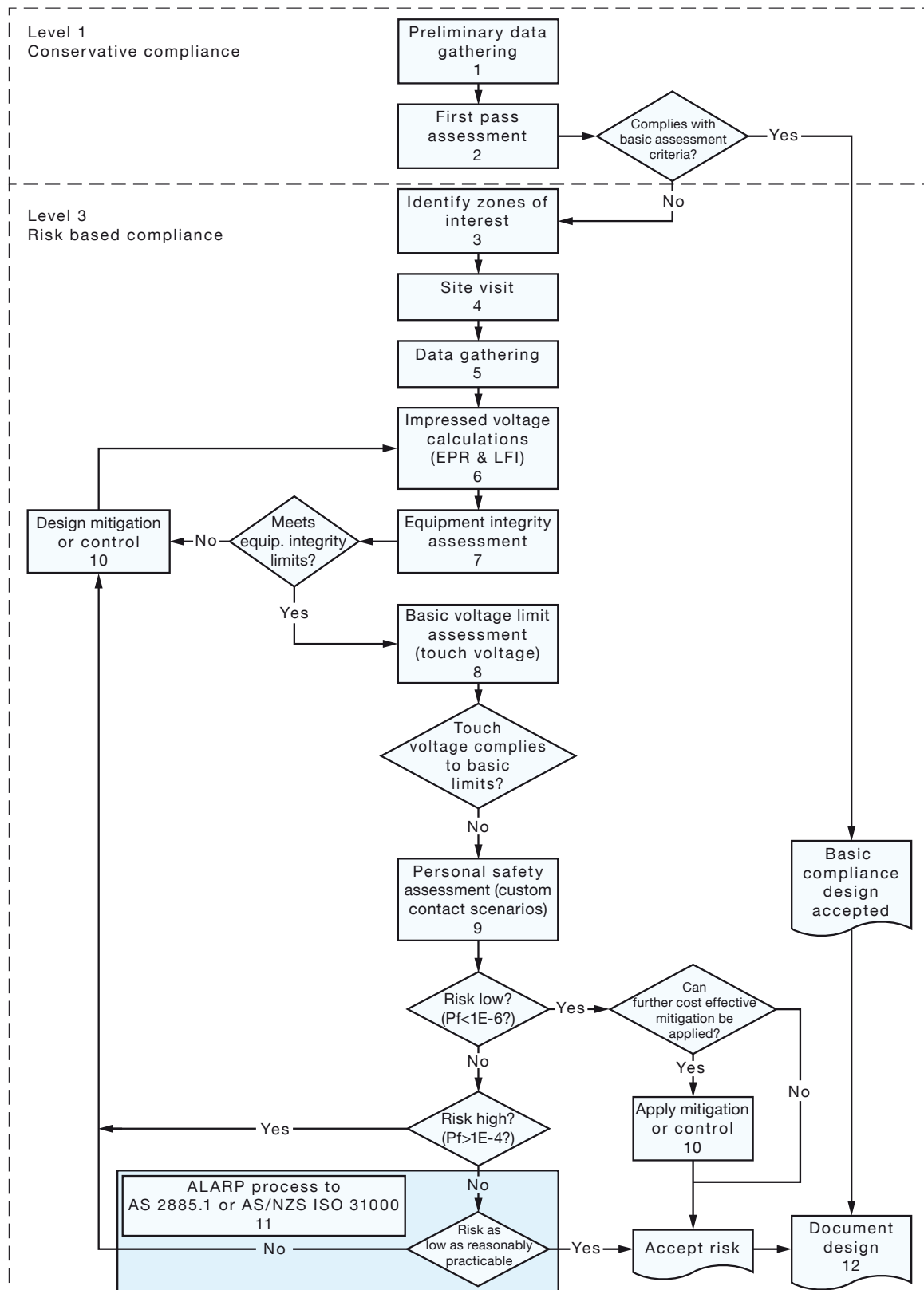


FIGURE 5.1 ELECTRICAL HAZARD DESIGN PROCESS